1. INTRODUCTION

Delightql is a logic-inspired query language that transpiles to SQL. This document provides a reference to the language via an enumeration of all of its features.

Each feature comes with at least one example and a short description to motivate usage. While structured like an introduction by beginning with foundations and growing from there, this reference is not a beginner's text and presupposes a familiarity with SQL. A reader with such a background will find features easier to locate and to understand.

The reference is organized into sections familiar to SQL users: DQL, DDL, and DML.

- **Data Querying Language (DQL)**: Any feature that is used to return a result via querying. All examples here may be directly run in the delightql read-eval-print loop (REPL).
- **Data Definition Language (DDL)**: Any feature that is used to create or drop tables, views or functions. These correspond to SQL DDL statements and to Prolog assertion-mode rules.
- **Data Manipulation Language (DML)**: Any feature that is used to modify an existing set of data, i.e. `update`, `delete`, or `insert`.

- **Keywords, Identifiers, and Ground Terms**: An index of lexicographical syntax needed to identify identifiers, constant (ground) values, and keywords.
- **Precedence**: The precedence rules for parsing operators and expressions, both at the level of table expressions and of domain expressions.
- **Directives**: An index of the special pseudo-relations and operators used to configure the language, and attach databases.
- **System Tables**: A listing of the system tables available to introspect code, execution, and the state of the databases.

Throughout this reference, examples of SQL illustrate how a delightql expression could be transpiled. Such SQL examples should be read as both descriptive of translation semantics and rigorous to final results. Actual SQL from these delightql examples may differ – for one, different SQL targets [1] will likely have different implementations.

1 The term target indicates the dialect of SQL which will be the transpile target for the delightql transpiler.

As an example of this point, consider the following SQL for an `OUTER JOIN`.

SQL

```sql
SELECT *
FROM employee FULL OUTER JOIN department
  ON employee.DepartmentId = department.DepartmentId;
```

Some SQL dialects do not have this native syntax, but can achieve the same result, with a lot of ceremony – example copied from:[s.n24,].

```SQL
SELECT
  employee.LastName,
  employee.DepartmentId,
  department.DepartmentName,
  department.DepartmentId
FROM employee
JOIN department
  ON employee.DepartmentId = department.DepartmentId
UNION ALL
SELECT
  employee.LastName,
  employee.DepartmentId,
  CAST(NULL AS varchar(20)),
  CAST(NULL AS integer)
FROM employee
WHERE
  NOT EXISTS (
    SELECT *
    FROM department
    WHERE
      employee.DepartmentId = department.DepartmentId
  )
UNION ALL
SELECT
  CAST(NULL AS varchar(20)),
  CAST(NULL AS integer),
  department.DepartmentName,
  department.DepartmentId
FROM department
WHERE
  NOT EXISTS (
    SELECT *
    FROM employee
    WHERE
      employee.DepartmentId = department.DepartmentId
  );
```

Both the above queries execute a full outer join with significantly different syntax while capturing the same semantics [2]. In such circumstances, this reference will choose the simplest and clearest SQL.

2 It is operationally easy to define semantic equality in our discussions: if two different queries under all circumstances produce the exact same table (same schema, same cardinality), then they are semantically equivalent

1.1. TERMINOLOGY

Delightql takes inspiration from the logic programming world as well as from SQL, so there will be many places in this reference where terminology from both may be used.

As a mini-tutorial for those unfamiliar, consider the following table of terminology equivalences:

SQL	logic programming
database	database
query	query
query	goal
query execution	unification and resolution
table	relation
table	predicate
table	relation/predicate of only ground terms (extensional)
view	predicate rule (intensional)
view with recursive CTE	predicate rule with multiple clauses and recursion
column	dimension
column	logic variable (LVar)
row	fact
tuple	fact
value	ground term
table definition	rule
view definition	rule
join	logical and
join	conjunction
exists (semijoin)	provable
not exists (antijoin)	not provable
union	logical or
union	disjunction
union	predicate rule with multiple clauses
insert row	assert a fact
delete row	retract a fact
update row	retract and assert fact
number of columns	predicate arity
number of columns	predicate dimensionality
table-valued function	higher order predicate

Table 1: SQL and logic programming terminology equivalences

This table is neither complete nor free of caveats. There is no novelty[3] to this congruence as Codd and Kowalski both showed how relational algebra query languages and Prolog respectively could be built from predicate calculus. Many disciplines starting in the 1970s continue to examine the ways in which these technologies are two sides of the same coin, but may still yet inform the other.[4]

3 in the nothing new under the sun sense

4 A notable example of this cross-pollination is how the academic research from deductive databases and Datalog provided the semantics – and permission – for SQL to adopt recursive common table expressions

Some features from one area have no equivalence in the other. For instance, the SQL `NULL` has no logic programming analog, and features that derive from this distinction (like outer joins) likewise find no purchase.

1.1.1. Core Terminology

Some terms in this reference are used often enough to warrant the following few early paragraphs. These terms are

- domain
- functor
- predicate and relation and their distinction
- sigilization

1.1.1.1. Domain

The term domain is used throughout this book much in the same way it is used throughout mathematics, as the set of possible values for a given quantity. In SQL parlance, this is not to be confused with type, as the domain of heights should not be confused with the domain of Kelvin temperatures even though both could be modeled as positive real numbers.

Highlighting the term domain is done to create an emphasis on non-domain things. Delightql makes this distinction by asserting that things are either domain values or predicate values, either domain expressions or predicate expressions.

This is a somewhat artificial delineation as tables/predicates being cartesian products have their own very real input space and domain.

To be concrete:

- **Domain values** include `1`, `"roger"`, and `true`; domain expressions include `1+2` and `upper("roger")`.
- **Predicate values** include `employee`; predicate expressions include `generate_series(1,10)` or `(select i_am_a_subquery from inner) as newtable`.

1.1.1.2. Functor Form, or just Functor

A functor form is an identifier followed by a pair of parentheses and the arguments contained within. This definition is syntactic only, and has no assigned semantics until we establish a context. With apologies to Prolog, we shorten the term **functor form** to just **functor**.

Within the context of delightql a functor is usually understood to be a **table** and **always** understood to be a predicate (as predicates generalize tables).

```delightql
// Access the table foo and its three columns
// which we call a,b, and c
foo(a,b,c)
```

```delightql
// Access the table bar and all its columns
bar(*)
```

In the context of delightql and most logic languages, the functor notation is self-denoting. This means several things, but practically we can say the following:

- With functor notation, traditional notions of inputs and outputs are blurred, and often meaningless (each argument may be either input or output).
- A functor cannot be assigned to a (scalar) variable because it denotes itself **as a relation**, and not as a scalar (domain value).

In contrast, most other programming languages use functor syntax to denote a function and/or (perhaps) a subroutine.

```
foo(a,b,c)
```

implies

- if a subroutine: an execution/call only
- if a function: an execution/call and substitution by the domain value that it produces.

Under these languages, arguments are passed into a function (`a`, `b`, and `c`) and are consumed. Here, the function syntax is operationally equivalent to the value it returns, and thus can be assigned to domain variables.

That delightql, like Prolog, assigns the concept of a **predicate/relation** to the functor does not mean the absence of functions.

In Prolog, functions re-use the predicate functor syntax via the designation of a known argument (called a mode) to be the output. Prolog has additional nuances about functions which we will sidestep.

Delightql provides a special syntax that remains reminiscent of a relation: a functor with a colon `:` between the identifier and the pair of parentheses, which we will call a **function functor**.

delightql

```
count:(*)
length:(last_name)
foo:(x,y,z)
```

The colon asks us to read `foo of x and y and z` or `length of last_name`.

1.1.1.3. Predicate vs Relation vs Table

The terms predicate, relation, and table lack any universal authority, yet each carries emphasis depending on whom you're talking to. This section exists not for philosophy but because Prolog, SQL, and therefore delightql all take different positions at different times on whether these are separate concepts, and how strongly to emphasize the chosen mental model.

A predicate/relation/table can be viewed as:

- An arbitrary subset of a Cartesian product (the mathematical view)
- A named storage entity for data queries (the database view)
- A named evaluator of truth in logical statements (the logic view)
- A generalization of functions (the relational view delightql emphasizes)

SQL treats relation and table as interchangeable, embracing the first two definitions. It reserves predicate for built-in truth evaluators over traditional domains like numbers and strings – as in `where age>20 and last_name like "%son"`, where two predicates compose into one.

Prolog favors predicate, with occasional references to relation and rare references to table. But it maps its term to all three definitions above. A Prolog predicate can be stored data, a logical assertion, or a computable relationship.

Delightql uses these terms interchangeably, with some deliberate emphasis. It borrows from Prolog in favoring predicate for tables (extensional data), views (intensional data derived from extensional data), and built-in domain predicates like =, <, >, and `like`.

Like Prolog, delightql recognizes an operational difference between predicates resolvable from ground truths (finitary – backed by actual stored tuples) and those expressing relations over infinities. To wit, there is no table enumerating all pairs where one number is less than another. Prolog restricts such non-Herbrand expressions via moding. Delightql similarly won't let you write the equivalent of `select left_hand from ">" where right_hand=3`.

There is one more definition worth surfacing:

- A predicate is a function of truth – given a tuple, it returns membership (true/false)

This is just a restatement of "named evaluator of truth," but the framing foregrounds the boolean nature of predicates. In such situations, we ask not what data they contain, but whether a given tuple belongs. Delightql emphasizes this framing for what SQL calls semi-joins (`EXISTS` queries) and what Prolog expresses through provability contexts like negation-as-failure (`\+`). In these cases, we don't care what the predicate returns – only whether it succeeds.

1.1.1.4. Sigilization

Delightql has few keywords compared to SQL. Where SQL uses words, delightql uses symbols.

Throughout this reference, the term sigilization describes delightql's practice of representing operators with non-alphanumeric symbols rather than keywords.

For example, delightql sigilizes the **DISTINCT** relational operator with a `%` symbol followed by parentheses:

delightql
```
users(*) |> %(last_name)
// SQL: SELECT DISTINCT last_name FROM users
```

To continue this example, delightql recognizes that `GROUP BY` is simply `DISTINCT` extended with aggregation. The same `%` sigil handles both – separate grouping columns from aggregate functions with ~> to get the equivalent of SQL's `GROUP BY`:

delightql
```
users(*) |> %(last_name ~> count:(*), sum:(salary) as
salary_by_last_name)
// SQL: SELECT count(*), sum(salary) as
salary_by_last_name FROM users GROUP BY last_name
```

1.2. FORMATTING

All code examples will be inset within colored text boxes, annotated with the primary language. These annotations are located atop the upper right corner of the code box.

- Boxes annotated with `Sql` are explanatory transpilations
- Boxes annotated with `delightql` are delightql examples of query expressions that are available during query mode
- Boxes annotated with `delightql AM` are delightql examples of assertion mode constructs, for defining rules, tables, updates, etc. (DDL and DML).

The below example shows a simple query in query mode:

delightql
```
employee(*)
```

and the next shows assertion mode:

delightql
```
 /* Sigma Rule, column is moded to require instantiation
*/
 empty(column) :- {}=column
 empty(column) :- trim:(column)=""
 empty(column) :- +no_data(column)
```

Inline text follows the following typography convention:

- Sql keyword syntax is italicized in fixed-width font code blocks, such as *`update`*, or *`select`* or *`drop`*.
- Identifiers (regardless of language) are styled as monospace code (e.g. `employee`, or `last_name`) and are not italicized.
- Delightql sigils are bounded by double parentheses, ((( ))). This is done to prevent confusion by separating the punctuation belonging to the language from the punctuation of the reference. Examples: `,`, or `|>`. To repeat: only the syntax within the double parentheses ((( ))) is valid delightql syntax.
- Delightql sigils are often accompanied by their sigil name in a capitalized bold font. These names provide easier search values within the reference. Examples: **R-PIPE** for `|>`, **GROUP-MODULO** for `%(◌)`. Both the sigils and the sigil are found in the [DqlVoc] section of this reference.
- Certain phrases will be italicized, indicating that there is a formal definition for this phrase and found in a glossary at the end of the reference. Examples:
  - stacked notation
  - sigma clauses
  - column ordinality
  - current piped relation
  - etc.

2. DATA QUERY LANGUAGE (DQL)

The heart of both delightql and SQL is the query expression, also called a table expression. A query expression is a unit of code that returns exactly one table. Here, table is synonymous with predicate or relation, regardless of whether the data is persisted via CREATE TABLE. [5]

The majority of delightql lives in this section; mastering it is prerequisite to understanding DDL and DML.

A query's meaning is identical to the table it produces. This substitutability is key to composability: through subqueries and CTEs, query expressions become recursively inductive to any depth. Delightql encourages a particular style of composition that will become evident within a few pages – pipelining a relation through transformations, left to right, with consistent associativity and scoping.

5 More typically, these results are anonymous and ephemeral – the output of execution within the REPL.

2.1. FROM

Every delightql query begins with a source: one or more tables from which to draw data. SQL calls this selection [6], but we will call this access or sourcing.

6 In contrast to Codd's original paper, where selection (σ) denoted row filtering–what SQL now calls WHERE.

2.1.1. All Columns

delightql

```
employee(*)
```

*

The glob `*` in argument position requests all columns from a table – equivalent to `SELECT * FROM employee`. This is the most common way to source data in delightql.

2.1.2. Argumentative Access

Arguments within the functor bring columns into scope by position.

```delightql
employee(EmployeeId  , LastName ,
         FirstName   , Title    , ReportsTo,
         BirthDate   , HireDate , Address, City,
         State       , Country  , PostalCode,
         Phone       , Fax      , Email )
```

This binds each identifier to the column at that ordinal position in the table definition. The arity must match exactly – if `employee` has 15 columns, the functor must have 15 arguments.

The identifiers you choose become the column names in scope of the position having the identifier.

```delightql
employee(a, b,  c,  d,
         e,   f, g,   h, i,
         j,  k,   l, m,   n,  o )
```

This makes argumentative access error-prone for wide tables. Prefer named access (covered later) when arity exceeds a handful of columns.

2.1.2.1. Case insensitivity

Delightql is case-insensitive. [7] The following all refer to the same identifier:

- `employeeid`
- `EmployeeId`
- `EMPLOYEEID`

[7] In contrast to Prolog, where capitalization distinguishes variables from atoms.

2.1.2.2. Stropping

When a name collides with a keyword or contains illegal characters (spaces, for instance), delimit it with backticks: `` `Employee Id` ``.

2.1.3. Aliasing a Table

```delightql
employee(*) as e
```

The `as` keyword assigns an alias to a table. Once aliased, columns must be accessed through the alias – the original table name leaves scope.

SQL
```
select * from employee as e;
```

Aliases are often a convenience, but become necessary in contexts like self-joins.

2.1.4. Table Namespacing

delightql
```
hr.employee(*) as e
```

A dot-prefixed identifier namespaces the table. Here, `employee` lives within the namespace `hr`. What this namespace represents – schema in some databases, database in others – is implementation-dependent.

SQL
```
select * from hr.employee as e;
```

The namespace is the entire syntax before the dot and may include nesting using `::`. Namespaces are nested like file-system folders.

delightql
```
client1::production::hr.employee(*) as e
```

In the above example, `client1::production::hr` is the namespace where `client1` contains `production` which contains `hr`.

Namespaces are elements of the delightql runtime. The delightql programmer chooses the hierarchy and maps these to source structures. For more information, see the namespacing section of DDL.

2.1.5. Anonymous Table

delightql
```
_(1,2,3)
```

The underscore functor `_( )` declares a table inline, with literal values. Commas separate columns. This is equivalent to:

SQL
```
select 1,2,3;

select * from (values (1,2,3));
```

The underscore is the `FULL` sigil – a name for “no name.” [8]

8 The name `FULL` plays against `NULL`: where `NULL` matches nothing and has null potency, `FULL` matches everything and is full of potential.

Note the two anonymous tables in play: the inline table declared with `_( )` and the result table returned by the query itself. The term anonymous table in this reference denotes the former – tables whose values are defined inline and whose names are discarded. [9]

9 An anonymous table is a query-mode construct, despite its syntactic resemblance to assertion-mode fact instantiation.

2.1.6. Stacked Notation and Multiple Rows

Multiple rows are expressed with the SEMI-OR sigil `;`, a disjunction operator:

delightql
```
_(1,2;10,20)
```

SQL
```
select 1,2
  UNION ALL
select 10,20;
```

Semicolon binds looser than comma, so rows stack naturally without parentheses. This stacked notation appears throughout delightql – anywhere multiple clauses or rows would otherwise require repeating functor syntax. [10]

10 Stacked notation is essentially syntactic sugar: it reduces redundant functor notation in both assertion mode and anonymous tables. See the glossary for examples.

2.1.7. Naming the Columns of Anonymous Tables

The columns in the examples so far have been positional – they have ordinal positions but no names. Delightql allows positional-only access, but also provides syntax for naming columns.

delightql
```
  _( first, second @ 1,2;10,20;100,200)
```

SQL
```
select 1 as first ,2 as second
  UNION ALL
select 10,20
  UNION ALL
select 100,200;
```

The **ATOP** sigil `@` separates column names (comma-delimited) from the stacked data that follows. This three-row, two-column table now has columns named `first` and `second`.

ATOP has an alternate form: three or more dashes. The following are all equivalent:

- `@`

- `---`
- `--------`
- `----------------------`

The dashed form enables formatted table literals:

```delightql
_(
 id,first_name   , last_name , email
 ------------------------------------------------
 0,"Gusti"       , "Parlor"  , "gparlor0@phoca.cz"  ;
 1,"Diane-marie" , "McHenry" , "dmchenry1@dot.gov"  ;
 2,"Ced"         , "Mainds"  , "cmainds2@goo.ne.jp" ;
 3,"Bren"        , "Berndsen", "bberndsen3@gr.com"
)
```

2.1.8. Sparse Anonymous Tables

When most columns in a wide anonymous table are NULL, data rows become verbose and error-prone. **Sparse columns** solve this: mark optional columns with `?` in the header, then fill only the ones you need per row.

```delightql
_(column, type, nullable?, default?, check?,
primary_key?, unique?
-------------------------------------------------------------------
  "id",     "INT",    _(primary_key @ "true") ;
  "name",   "TEXT" ;
  "email",  "TEXT",   _(unique @ "true") ;
  "salary", "DECIMAL",_(check @ "salary>0"))
```

Columns without `?` are **positional** – every row must supply them, in order. Columns with `?` are **sparse** – unfilled sparse columns default to NULL. If sparse columns are used, they must come after the required columns.

2.1.8.1. Sparse fills

A sparse fill uses anonymous table syntax `_(col @ val)` to assign a value to a named sparse column. Fills appear after the positional values in a data row:

```delightql
// Single fill
"id", "INT", _(primary_key @ "true")

// Multiple separate fills
"id", "INT", _(primary_key @ "true"), _(nullable @
"false")

// Combined fill: multiple sparse columns in one
expression
"id", "INT", _(primary_key, nullable @ "true", "false")
```

In a combined fill, column names and values are matched positionally: `primary_key` gets `"true"`, `nullable` gets `"false"`.

2.1.8.2. No fills

When a row supplies no fills, all sparse columns are NULL:

```delightql
_(a, b?, c?
  --------
  1 ;
  2 ;
  3)
```

This is equivalent to `_(a, b, c @ 1, null, null; 2, null, null; 3, null, null)`.

2.1.8.3. All sparse

A table may have no positional columns at all:

```delightql
_(x?, y?
  ------
  _(x @ 1) ;
  _(y @ 2) ;
  _(x, y @ 3, 4))
```

2.1.9. Higher-Order Predicates

Delightql supports higher-order predicates–predicates that accept tables (or scalars) as parameters and return a table. SQL calls these table-valued functions.

```delightql
clean_employees(hr.employee(*))(*)
```

Here, `clean_employees` is a higher-order predicate that takes `hr.employee(*)` as its parameter.

The transpiled SQL depends on how the predicate was defined. [11] Given this definition:

11 Defining higher-order rules is covered in the DDL section.

delightql
```
clean_employees(T(*))( * ) :-
  T(*) as t
    |> $(trim:())( t.LastName, t.FirstName)
    |> $(to_iso:())( t.BirthDate, t.HireDate)
    |> -( SSN)
```

the query `clean_employees(hr.employee(*))(*)` produces:

SQL
```
select
    EmployeeId,
    trim(LastName)    as LastName,
    trim(FirstName)   as FirstName,
    Title,
    ReportsTo,
    to_iso(BirthDate) as BirthDate,
    to_iso(HireDate)  as HireDate,
    Address,
    City,
    State,
    Country,
    PostalCode,
    Phone,
    Fax,
    Email
from employee;
```

Higher-order predicates are structurally typed by the columns they reference. [12] In this example, any table with `LastName`, `FirstName`, `BirthDate`, `HireDate`, and `SSN` qualifies:

12 This resembles duck typing: delightql has no formal type layer, but detects which columns the predicate body requires. Any table providing those columns is a valid argument.

delightql
```
clean_employees(batch.employee_2019(*))(*)
```

The pipeline form (covered later) is equivalent:

delightql
```
batch.employee_2019(*)
    |> clean_employees(*)
```

2.2. ORDER BY

Delightql, like SQL, has order by. The ORDER-BY operator is an octothorpe-prefixed functor `#()` applied after a pipe:

delightql
```
employee(*)
    |>  #(FirstName,LastName)
```

SQL
```
select
  *
from employee order by FirstName, LastName;
```

Columns appear in the SQL in the order given. Collation modifiers work as in SQL–with keywords:

delightql
```
employee(*)
    |>  #(Salary descending,LastName ascending)
```

SQL
```
select
  *
from employee order by Salary desc, LastName asc;
```

> `Order By` has no meaning in pure relational algebra, where relations are unordered sets. SQL has never been true to theory; delightql is equally cavalier. To admit order-by as a first-class relational operator, delightql takes two positions:
>
> - Relations are ordered sequences of tuples, not sets. [13]
> - A parametric mechanism maps domain orderings onto tuple orderings. [14]

13 A sequence captures this notion.

14 We can imagine every tuple contains a hidden column `#`. Absent an explicit ordering, this column holds arbitrary values. Given `order by my_column`, the tuples reorder and # recalculates accordingly.

LIMIT

Limit the number of tuples returned using the **TUPLE-ORDINAL** sigil `#` in a predicate position:

delightql
```
employee(*) , # < 20
```

SQL
```
select * from employee limit 20;
```

Read this as: “all columns of employee where the implicit row ordinal is less than 20.”

Limit affects only cardinality, not schema.

Order of operations matters. Delightql evaluates left to right, so these two queries differ:

delightql
```
employee(*), department(*.(DepartmentName)), #<20
```

SQL
```sql
select
  *
from employee join department using(DepartmentName)
  limit 20;
```

delightql
```
employee(*), #<20, department(*.(DepartmentName))
```

SQL
```sql
select
  *
from (select * from employee limit 20)
  join department using(DepartmentName);
```

2.4. PROJECTION

Projection retains a subset of columns from a relation. In SQL, this is the list between SELECT and FROM.

2.4.1. Project Retain

delightql
```
employee(*)
  |>  (FirstName , LastName)
```

SQL
```sql
select
  FirstName,
  LastName
from employee;
```

The R-PIPE `|>` passes a relation to the PROJECT operator `( )`. Columns listed inside are retained; all others are discarded.

The pipe creates a scope barrier: columns to the left are no longer in scope after the projection. Only the projected columns continue forward.

Projections can be chained:

delightql
```
employee(*)
  |>  (FirstName , LastName)
  |>  (FirstName )
```

SQL
```
select FirstName from employee;
-- -- optimized from:
-- select FirstName
--   from (
--     select
--       FirstName,
--       LastName
--     from employee);
```

Delightql (and SQL optimizers) will simplify redundant intermediate projections. But scope is enforced at each step–this will not work:

delightql
```
// Error: FirstName not in scope
employee(*)
  |>  (LastName)
  |>  (FirstName)
```

After line 2, only LastName exists in the piped relation.

2.4.2. Rename

Rename a column during projection with as:

delightql
```
employee(*)
  |>  (FirstName as f, LastName)
```

SQL
```
select
  FirstName as f,
  LastName
from employee;
```

2.4.3. Generalized Projection

Columns can be transformed during projection using domain functions:

delightql
```
employee(*)
    |>  ( upper:(FirstName) as f,
          upper:(LastName) as LastName,
          3 + Salary as salary_plus_three)
```

SQL
```
select
  upper(FirstName) as f,
  upper(LastName) as LastName,
  3 + Salary as salary_plus_three
from employee;
```

Note the colon in `upper:(FirstName)`. This distinguishes functions from relations – `foo(A,B)` is a relation; `foo:(A)` is a function.

> Aggregate functions are not permitted in projection. See the sections on `distinct` and `group by` for aggregate usage. Delightql will reject known aggregates, but cannot detect user-defined aggregates–these will transpile as if scalar.

Other functions – 'case', 'case select', concatenation, windowing/analytic functions, and operators – are covered in the function chapter of this reference.

2.4.4. Argumentative Projection

Columns can be projected by position using argumentative access. The FULL sigil `_` discards unwanted positions:

delightql
```
employee(EmployeeId , LastName , _ , _ ,
        _ , _ , _ , _ , _ ,
        _ , _ , _ , _ , _ , _ )
```

SQL
```
select
  EmployeeId,
  LastName
from employee;
```

Only the first two columns are retained; the rest are projected away. The identifiers `EmployeeId` and `LastName` name the columns in the result – matching the underlying column names here, though positional access can also rename by using a different identifier.

As with argumentative positional access, this notation is brittle for wide tables – prefer named projection when arity exceeds a handful of columns (see Argumentative Positional Access).

2.4.5. Project Out

The PROJECT-OUT operator subtracts columns from a relation:

delightql
```
employee(*)
  |> -(BirthDate, Email)
```

SQL
```
select
    EmployeeId,
    LastName,
    FirstName,
    Title,
    ReportsTo,
    --  BirthDate, -- column projected out
    HireDate,
    Address,
    City,
    State,
    Country,
    PostalCode,
    Phone,
    Fax,
    -- Email
from employee;
```

All columns except `BirthDate` and `Email` are retained. This is particularly useful for wide tables where listing retained columns would be tedious.

2.4.6. Map Covering

The MAP-COVER operator `$( · )( · )` applies a function across specified columns while preserving all others:

delightql
```
employee(*)
  |> $(upper:())( LastName, FirstName, Title, ReportsTo)
```

SQL
```
select
    EmployeeId,
    upper(LastName)  as  LastName,
    upper(FirstName) as  FirstName,
    upper(Title)     as  Title,
    upper(ReportsTo) as  ReportsTo,
    BirthDate,
    HireDate,
    Address,
    City,
    State,
    Country,
    PostalCode,
    Phone,
    Fax,
    Email
from employee;
```

The first parentheses contain the function; the second lists the target columns. The function `upper:()` is written as arity-0 – a curried form where the column value fills the implicit first argument. [15]

15 This notation borrows from Elixir's pipe conventions.

Map covering:

1. Applies the function to each listed column
2. Renames results to their original column names
3. Passes through unlisted columns unchanged
4. Preserves column ordinality

Because unlisted columns pass through, transformations can be chained:

delightql
```
employee(*)
  |> $(upper:())( LastName, FirstName, Title, ReportsTo)
  |> $(to_iso:())( BirthDate, HireDate)
```

Composing functions. When multiple functions apply to the same columns, three options exist:

Chained covers (repetitive but clear):

delightql
```
employee(*)
  |>  $(upper:())(FirstName,LastName)
  |>  $(trim:())(FirstName,LastName)
```

Containment composition using F-PARAM `@` as a placeholder:

delightql
```
employee(*)
  |>  $(trim:(upper:(@)) )(FirstName,LastName)
```

Pipe composition using F-PIPE `/->`:

delightql
```
employee(*)
 |>  $(upper:() /-> trim:() )(FirstName,LastName)
```

All three produce:

SQL

```
select
    EmployeeId,
    trim(upper(LastName))  as  LastName,
    trim(upper(FirstName)) as  FirstName,
    Title,
    ReportsTo,
    BirthDate,
    HireDate,
    Address,
    City,
    State,
    Country,
    PostalCode,
    Phone,
    Fax,
    Email
from employee;
```

2.4.7. Basic Dimension Covering

The BASIC-COVER operator `$$(  )` transforms individual columns without the curried function syntax:

delightql

```
employee(*)
  |> $$( "--------" as Phone, upper:(State) as State)
```

SQL

```
select
    EmployeeId,
    LastName,
    FirstName,
    Title,
    ReportsTo,
    BirthDate,
    HireDate,
    Address,
    City,
    upper(State) as State,
    Country,
    PostalCode,
    '--------' as Phone,
    Fax,
    Email
from employee;
```

Each transformed column requires an `as` modifier – this identifies which columns are being replaced. Unlisted columns pass through in their original ordinality. Referencing a nonexistent column is an error.

2.4.8. Conditional Covering (If-Only)

The IF-ONLY sigil `|` constrains which rows a cover applies to. Rows not matching the predicate pass through unchanged.

Map-cover with if-only:

delightql
```
employee(*)
  |> $(upper:())(LastName, FirstName | Department =
"Executive")
```

SQL
```
SELECT
  EmployeeId,
  CASE
    WHEN Department = 'Executive' THEN upper(
      LastName
    )
    ELSE LastName
  END AS LastName,
  CASE
    WHEN Department = 'Executive' THEN upper(
      FirstName
    )
    ELSE FirstName
  END AS FirstName,
  Title,
  Department,
  ReportsTo,
  BirthDate,
  HireDate,
  Address,
  City,
  State,
  Country,
  PostalCode,
  Phone,
  Fax,
  Email
FROM employee;
```

The predicate follows the column list, separated by `|`. This mirrors the aggregate if-only `count:(col | pred)` – the `|` always sits between the operands and the condition.

Without if-only, the function applies to all rows. With if-only, the function applies only to matching rows; non-matching rows retain their original values.

Basic-cover with if-only:

```delightql
employee(*)
  |> $$("REDACTED" as Phone, "---" as Fax | Department =
"Executive")
```

```sql
select
    EmployeeId,
    LastName,
    FirstName,
    Title,
    Department,
    ReportsTo,
    BirthDate,
    HireDate,
    Address,
    City,
    State,
    Country,
    PostalCode,
    case when Department = 'Executive'
         then 'REDACTED' else Phone end as Phone,
    case when Department = 'Executive'
         then '---' else Fax end        as Fax,
    Email
from employee;
```

The predicate goes at the end of the item list, after the last as target.

Composability. If-only composes with function composition and chaining:

```delightql
employee(*)
  |> $(upper:() /-> trim:())(FirstName, LastName |
Country = "USA")
```

If-only is syntactic sugar over CASE expressions. The equivalent without if-only:

```delightql
employee(*)
  |> $$( _:(Department = "Executive" -> upper:
(LastName);  _ -> LastName)  as LastName,
         _:(Department = "Executive" -> upper:
(FirstName); _ -> FirstName) as FirstName)
```

2.4.9. Regular Expression Column Addressing

A regular expression can select columns by name pattern:

```delightql
employee(*)
  |> ( /Date/ )
```

SQL
```
select
    BirthDate,    -- matches Regex /Date/
    HireDate      -- matches Regex /Date/
from employee;
```

Both `BirthDate` and `HireDate` match the pattern `/Date/`. The regex applies only to column names (not namespaces or indexes). Delightql uses UNIX BRE syntax within the REGEX sigil `/  /`. Append `i` for case-insensitive matching: `/date/i`.

Restrictions. Regex column addressing may only appear in **PROJECT-IN**, **PROJECT-OUT**, or the second parentheses of **MAP-COVER**. It cannot:

- Be followed by `as`
- Be passed directly to a function
- Appear in **EMBED** `+(  )`, **BASIC-COVER** `$$(  )`, **RENAME-COVER** `*(  )`, or **GROUP-MODULO**

2.4.10. Rename Cover

The RENAME-COVER operator `*(  )` renames specified columns while passing all others through:

delightql
```
employee_2019(*)
  |> *( FamilyName as LastName)
```

SQL
```
select
    EmployeeId,
    FamilyName as LastName,
    FirstName,
    Title,
    ReportsTo,
    BirthDate,
    HireDate,
    Address,
    City,
    State,
    Country,
    PostalCode,
    Phone,
    Fax,
    Email
from employee_2019;
```

Rename cover preserves column count and column ordinality – only the names change.

2.4.11. Embedding

The EMBED operator `+( )` adds a new column to a relation, placed after existing columns:

delightql
```
employee_2019(*)
  |> +(  strftime:('%Y',BirthDate) - 2 as
two_years_before_birth )
```

SQL
```
select
    *,
    strftime('%Y',BirthDate) - 2 as
two_years_before_birth
from employee;
```

This is equivalent to `|> (*, expr as name)`. The embed syntax makes the intent explicit: the relation is unchanged except for the added column.

2.4.12. Map Embedding

The EMBED-MAP operator `+$( )( )` applies a function across columns and creates new columns from the results (rather than replacing the originals):

delightql
```
f_to_c:(f) :- (f - 32.0)*0.5556
f_to_k:(f) :- f_to_c:(f)+273.15

?- boston_temps(*)
     |> +$(f_to_c:() as :"{@}_c")( /_temp/ )
     |> +$(f_to_k:() as :"{@}_k")( /_temp/ )
```

SQL
```
SELECT
  month,
  daily_max_temp,
  daily_min_temp,
  daily_avg_temp,
  (daily_max_temp - 32.0) * 0.5556 AS daily_max_temp_c,
  (daily_min_temp - 32.0) * 0.5556 AS daily_min_temp_c,
  (daily_avg_temp - 32.0) * 0.5556 AS daily_avg_temp_c,
  (daily_max_temp - 32.0) * 0.5556
  + 273.15 AS daily_max_temp_k,
  (daily_min_temp - 32.0) * 0.5556
  + 273.15 AS daily_min_temp_k,
  (daily_avg_temp - 32.0) * 0.5556
  + 273.15 AS daily_avg_temp_k
FROM boston_temps;
```

The first parentheses contain the function and an as qualifier with an F-STRING. The F-PARAM sigil `@` stands in for the column name, generating `daily_max_temp_c`, `daily_min_temp_c`, etc. The second parentheses specify the target columns–here, all columns matching `/_temp/`.

Unlike **MAP-COVER**, which replaces columns in place, **EMBED-MAP** preserves the originals and appends the transformed columns.

2.4.13. Projection Summary

The operators introduced so far are all **unary** – they transform a single relation. The following qualities characterize their behavior:

- **Column Cardinality Preserved**: The number of columns remains unchanged.
- **Column Ordinality Preserved**: Columns retain their relative order, with no intercalation of new columns among existing ones.
- **Column Names Preserved**: Existing columns keep their names (new columns do not affect this).
- **Table Cardinality Preserved**: The number of rows remains unchanged.
- **Table Ordinality Preserved**: Rows retain their order.

A quality is marked **Y** only if it holds under all circumstances; **N** if any case violates it.

	`( )`	`-( )`	`$( )( )`	`$$( )`
	Project	Project Out	Map Cover	Basic Map Cover
Column Ordinality Preserved	N	Y	Y	Y
Column Cardinality Preserved	N	N	Y	Y
Column Names Preserved	N	Y	Y	Y
Table Cardinality Preserved	Y	Y	Y	Y
Table Ordinality Preserved	Y	Y	Y	Y

Table 2: Preservation properties of Project, ProjectOut, MapCover, and BasicMapCover

	*( )	#( )	%( )
	Rename	Order By	Group Modulo
Column Ordinality Preserved	Y	Y	N
Column Cardinality Preserved	Y	Y	N
Column Names Preserved	N	Y	N
Table Cardinality Preserved	Y	Y	N
Table Ordinality Preserved	Y	N	N*

Table 3: Preservation properties of Rename, OrderBy, and GroupModulo

	+( )	+$( )
	Embed	Map Embed
Column Ordinality Preserved	Y	Y
Column Cardinality Preserved	N	N
Column Names Preserved	Y	Y
Table Cardinality Preserved	Y	Y
Table Ordinality Preserved	Y	Y

Table 4: Preservation properties of Embed and MapEmbed

One operator stands apart: GROUP-MODULO `%( )` preserves none of these qualities unconditionally. It captures both `DISTINCT` and `GROUP BY`, and is the subject of the next chapter.

2.5. DISTINCT AND GROUP BY

Distinct and group by are congruent operations. Their similarity is often a source of confusion:

```sql
select
  Department
from employee
  group by Department;

-- Produces the same result as:

select
  distinct Department
from employee;
```

Delightql reflects this congruence with unified syntax.

2.5.1. Distinct

The GROUP-MODULO operator `%( )` returns distinct combinations of the specified columns:

delightql
```
employee(*)
  |> %(Department)
```

SQL
```
select
  distinct Department
from employee;
```

Multiple columns return distinct combinations:

delightql
```
employee(*)
  |> %(Department, State)
  |> #(Department,State descending)
```

SQL
```
select
  distinct Department, State
from employee
    order by Department asc, State desc;
```

To deduplicate all columns – converting a multiset (bag) into a set:

delightql
```
employee(*)
  |> %(*)  //returns unique rows and removes duplicates
```

2.5.2. Group By

`Group by` extends distinct with aggregation. The AGG-AND sigil `~>` separates grouping columns (left) from reduced columns (right):

delightql
```
employee(*)
  |> %(Department ~>  count:(*) , sum:(Salary) )
```

SQL
```
select
  Department,  -- grouping column
  count(*),    -- reduced column
  sum(Salary)  -- reduced column
from employee
  group by Department;
```

Grouping columns may be expressions:

delightql
```
employee(*)
    |> %( Salary > 50000  as high_low,
          upper:(Department) ~>
            count:(*) ,
            avg:(Salary) )
```

SQL
```
select
  Salary > 50000 as high_low, -- grouping column
  upper(Department),  -- grouping column
  count(*),    -- reduced column
  avg(Salary)  -- reduced column
from employee
  group by upper(Department), (Salary > 50000) ;
```

2.5.3. Unsafe Reduced Column

Some SQL dialects prohibit non-aggregated columns in a group by, since the result would be arbitrary:

SQL
```
select
  Department,  -- grouping column
  LastName,    -- arbitrary reduced column
  FirstName   -- arbitrary reduced column
from employee
  group by Department;
```

The ACCEPT-ARB sigil ~? explicitly requests such columns:

delightql
```
  employee(*)
    |> %(Department ~? LastName, FirstName)
```

This is most useful when an aggregate function creates natural affinity to a specific row. [16]

16 SQLite provides useful semantics when the aggregate is `max()` or `min()` – it returns values from the row containing the max or min.

delightql
```
  employee(*)
    |> %(Department
          ~>
        max:(Salary)
          ~?
        LastName, FirstName)
```

2.5.4. Whole-Group Aggregate Functions

To aggregate without grouping, omit the grouping columns:

delightql
```
employee(*)
  |>  %( ~>  count:(*) , sum:(Salary) )
```

SQL
```
  select
    count(*),
    sum(Salary)
  from employee;
```

The GROUP-PIPE `~>` provides a shorter form for a single aggregate:

delightql
```
employee(*) ~>  count:(*)
```

Note. The **GROUP-PIPE** is different from the AGG-AND. This form replaces the `|>` pipe. It is pure sugar.

2.5.5. Internal Distinct

Some aggregates accept a distinct modifier on their input. The INNER-MODULO sigil `%` prefixes the column:

delightql
```
employee(*)
    |>  %( Department ~>
             count:(%LastName) ,
             count:(%BirthDate))
```

SQL
```
select
  Department,
  count(distinct LastName),
  count(distinct BirthDate)
from employee
  group by Department;
```

2.5.6. Filter Clauses

The IF-ONLY sigil `|` constrains which values enter an aggregate:

delightql
```
employee(*)
  |>  %( Department ~>
         count:(%LastName) ,
         count:(%BirthDate),
         count:(LastName | length:(LastName) > 10)
            as long_lastname_count)
```

For dialects supporting `FILTER`:

SQL

```
select
  Department,
  count(distinct LastName),
  count(distinct BirthDate),
  count(LastName)
    filter
      (where length(LastName) > 10) as
long_lastname_count
from employee
  group by Department;
```

For dialects without `FILTER`, delightql emits a `CASE` expression:

SQL

```
select
  Department,
  count(distinct LastName),
  count(distinct BirthDate),
  count(case when length(LastName) > 10
             then LastName else null) as
long_lastname_count
from employee
  group by Department;
```

2.5.7. Having

Filter on reduced columns by placing a predicate after the `group by`:

delightql

```
employee(*)
  |> %( Department ~> count:(*) as employee_count)
      ,  employee_count > 50
```

Read this as: “group employees by Department, count each group, then keep only groups with more than 50 rows.”

SQL

```
select
  Department,
  count(*) as employee_count
from employee
  group by Department
    having count(*) > 50;
```

> **Why does SQL have both WHERE and HAVING?**

SQL has an implicit order of operations. `WHERE` filters rows before grouping; `HAVING` filters groups after aggregation. The two keywords signal this distinction. [17]

The abstraction is leaky – most programmers soon recognize that `HAVING` is equivalent to wrapping in a subquery and filtering with `WHERE`:

SQL

```
SELECT Department, count(*) AS employee_count
FROM employee
GROUP BY Department
HAVING count(*) > 50;


-- equivalent to:

SELECT * FROM (
SELECT Department, count(*) AS employee_count
FROM employee
GROUP BY Department
) WHERE employee_count > 50;
```

Because delightql has explicit order of operations, no separate syntax is needed. The predicate simply follows the group by:

```
employee(*)
|> %(Department ~> count:(*) as employee_count),
employee_count > 50
```

Placing the filter earlier would be an error, `employee_count` does not exist until after the aggregation.

17 For a historical reflection on this issue, see [Dar24,].

2.6. DOMAIN FUNCTIONS

Functions on domains are ordinary functions–what most programming languages simply call “functions.” The qualifier “on domains” distinguishes them from functions on relations (table-valued functions, covered elsewhere). Here, “domain” means data type: the addition function + in `SELECT Salary + bonus FROM employee` expects numeric operands.

SQL provides several syntaxes for functions: standard functor notation, infix operators, and `CASE` expressions. This section covers how to call domain functions in delightql. For defining functions, see Function Definition.

Domain functions can appear anywhere a column is valid – they are substitutable for the value they compute:

- During projection, as a transformation of a column
- During selection, as a transformation prior to comparison
- During grouping, as a transformation prior to grouping
- During aggregation, as a reduction of multiple values

Delightql's default function syntax incorporates a colon: `foo:(x)` rather than `foo(x)`. This functional functor notation distinguishes functions from relations. [18]

18 Delightql's syntax derives from Prolog, where `foo(x,y)` denotes a relation. Functional functor notation marks the subset of relations that are functions – mappings that return exactly one value per input.

2.6.1. Standard Function Invocation

```delightql
employee(*),
  length:(LastName) > 5
  |> +( trim:(upper:(LastName)) as CapitalizedLastName)
```

Three functions appear in two contexts:

- `length:()` in a predicate (sigma clause)
- `trim:()` and `upper:()` in an embed, using containment composition

The colon signals to both compiler and programmer that the functor returns a domain value, not a relation.

2.6.2. Function Pipe Composition

The F-PIPE sigil `/->` composes functions left to right:

```delightql
employee(*), length:(LastName) > 5
  |> +( LastName /-> upper:() |-> trim:() as
CapitalizedLastName)
```

The pipe begins with a domain expression (a column, literal, or function call). Each subsequent function is in curried form – the piped value fills the first argument.

When the value belongs in a different argument position, use the F-PARAM sigil `@`:

```delightql
employee(*), length:(LastName) > 5
  |> +(  BirthDate /-> strftime:("%Y",@) as BirthYear )
```

The LAMBDA sigil `:( )` creates an inline function. The `@` marks where the piped value is placed.

```delightql
employee(*), length:(LastName) > 5
    |> +(  BirthDate /-> strftime:("%Y",@) |-> :( @ +
2) as BirthYearPlusTwo,
           BirthDate /-> strftime:("%Y",@) |-> sqrt:()
as SqrtOfBirthYear)
```

2.6.3. Domain Operators

Delightql supports standard arithmetic operators:

Sigil	Name	Arity
*	OP-MULT	Binary
+	OP-PLUS	Binary
-	OP-MINUS	Binary
-	OP-NEGATIVE	Unary
/	OP-DIV	Binary
%	OP-MODULO	Binary

Table 5: Arithmetic domain operators

No implicit precedence. Delightql requires explicit parentheses when mixing operators. There is no PEMDAS. [19] This is a deliberate design choice favoring clarity over convention.

19 See "Order of Operations" for the conventional rules delightql declines to adopt.

```delightql
_(first,second,third @ 1.3,20,30)
    |> ( 1 + (first / third),
        -third / ((first * second) / 23.33),
        (third % 11) - 42)
```

```sql
select
  1+(first/third),
  -third / ((first*second)/23.33),
  (third % 11) - 42
from (select 1.3 as first, 20 as second, 30 as third);
--  1.04333333333333|-26.9192307692308|-34
```

2.6.4. *Case* Simple

SQL's CASE expression serves as a switch statement. Delightql represents it as what it is: a function, and therefore a relation.

delightql

```
employee(*)
    |> +(  _:(Department @
             "engineering"  -> "tech";
             "data science" -> "tech";
             _              -> "other") as kind )
```

SQL

```
select
  *,
  case Department
    when 'engineering' then 'tech'
    when 'data science' then 'tech'
    else 'other'
  end as kind
from employee;
```

The ANON-FUNC sigil `_:(  )` creates an anonymous case function. The F-AND sigil `->` separates input patterns (left) from output values (right). The SEMI-OR sigil `;` separates cases. The header Department `@` binds the input to the Department column.

This is stacked notation applied to functions: the `->` acts as a special comma that declares a functional dependency – columns left of the arrow are inputs, columns right are outputs.

Named case functions. The same notation defines reusable functions in assertion mode:

delightql

```
department_kind(
  Department     -> kind
  ------------------
  "engineering"  -> "tech";
  "data science" -> "tech";
  _              -> "other"
)

?- employee(*)
  |> +(  department_kind:(Department) as kind )
```

The predicate `department_kind` is both a table (two columns, three rows) and a function (input determines output). The `-`

`>` tells the compiler which column is the input when invoked as a function.

Without `->`, the predicate is valid but not callable as a function:

```delightql
//WILL NOT WORK!! (at least if you want to use it for
function calls)
//    .. it is a perfectly acceptable predicate
department_kind("engineering"  , "tech")
department_kind("data science" , "tech")
department_kind( _             , "other")
```

[20]

20 Prolog calls these input/output declarations modes or adornments. Delightql's `->` serves the same purpose: columns left of the arrow must be instantiated inputs.

2.6.5. *Case* Search Function

Case search evaluates conditions rather than matching values. Two syntaxes exist.

Condition-first notation uses -> pointing to the return value:

```delightql
students(*)
    |> %(  _:( grade > 90              ->  "A";
           grade > 80, grade <=90  ->  "B";
           grade > 70, grade <=80  ->  "C";
           grade > 60, grade <=70  ->  "D";
           _                       ->  "F") as score
           ~> count:(*) )
    |>  #(score)
```

Conditions can be conjoined with `,` (and). For disjunction, use the keyword **or**:

```delightql
students(*)
    |> %(  _:( grade > 90  or apple_given="true" ->
"A";
             grade > 80, grade <=90            -> "B";
             grade > 70, grade <=80            -> "C";
             grade > 60, grade <=70            -> "D";
             _                                 -> "F")
as score
           ~> count:(*) )
    |>  #(score)
```

Like SQL's CASE, the first matching clause wins.

```delightql
members(*)
    |> (  profile_nm,
          account_nm,
          location,
          _:(
             "north india m" | location in ("in";"rajkot"),
profile_nm="sally";
             "north india f" | location in ("in";"rajkot");
             "pakistan f"    | location in ("pk"; "france"),
profile_nm="sally";
             "pakistan m"    | location in ("in";"rajkot")
        ) as continent )
    |>  #(profile_nm,account_nm)
```

2.6.6. Format Function and Strings

Format strings interpolate column values into text. The F-STRING sigil `:` prefixes a string literal:

```delightql
employee(*)
  |> +( :"{LastName}, {FirstName} making ${Salary}" as
readable)
```

```sql
select
    EmployeeId,
    LastName,
    FirstName,
    Title,
    ReportsTo,
    BirthDate,
    HireDate,
    Salary,
    Address,
    City,
    State,
    Country,
    PostalCode,
    Phone,
    Fax,
    Email,
    LatName || ', ' || FirstName || ' making $' ||
Salary as readable
from employee;
```

Braces `{ }` enclose column names. Format strings also permit the usage of the following escape sequences:

escape sequence	meaning
\n	newline

escape sequence	meaning
`\t`	tab
`\\`	backslash
`\q`	single quote (')
`\Q`	double quote (")

Strings in delightql are only double-quoted. Any double-quoted string without a colon is a raw string and accepts neither interpolation nor escape sequences. Delightql also uses the triple-double-quotes to make for easier embedding of double quotes. These too may be used as string interpolators with a preceding colon.

delightql

```
_(1) |> ("""
  This is a banner and
  has no \n as a newline escape
  but the ones you typed are
  there because they are the bytes
  you typed
  """)
```

delightql

```
_(1) |> (:"""
  This is a banner and
  HAS the \n as a newline escape
  AND the ones you typed are
  there because they are the bytes
  you typed.  Also, you can type a
  double-quote as " or \Q and a
  single-quote as ' or \q
  """)
```

2.6.7. Window/Analytic Functions

Window functions combine aggregation with per-row results. They aggregate over a dynamic window but return one value per row – still scalar functions by definition. [21]

21 Array languages are the closest analog in other programming paradigms.

delightql

```
employee(*)
    |> (EmployeeId,
        DepartmentId,
        Salary,
        dense_rank:( <~ %(DepartmentId),#(Salary)) as
ranking )
```

SQL

```sql
SELECT
  EmployeeId,
  DepartmentId,
  Salary,
  dense_rank() OVER (
    PARTITION BY
      DepartmentId
    ORDER BY Salary
  ) AS ranking
FROM employee;
```

The **F-OVER** sigil `<~` introduces the window specification. Everything before <~ is passed to the function; everything after defines the window frame.

Window specification syntax. Comma-separated, all optional:

- `%( )` – partition clause (one allowed)
- `#( )` – order clause (one allowed)
- `rows(from, to)`, `range(from, to)`, or `groups(from, to)` – frame specification (one allowed)

Frame Bounds:

Syntax	Meaning
.	current row
_	unbounded
n	n preceding
+n	n following
-n	n preceding (explicit)

Table 7: Window frame bound syntax

Examples:

delightql

```
  ntile:( 10  <~  %(DepartmentId),#(-Salary), groups(_,_))
  ntile:( 10  <~  %(DepartmentId),#(-Salary), groups(+1,_))
  ntile:( 10  <~  %(DepartmentId),#(-Salary), rows(1,.))
  ntile:( 10  <~  %(DepartmentId),#(-Salary), rows(_,-(upto*2)))
  ntile:( 10  <~  %(DepartmentId),#(-Salary), range(.,upto*2) )
```

SQL
```
  ntile(10) over
    ( partition by DepartmentId order by Salary desc
      groups between
        unbounded preceding and unbounded following)
  ntile(10) over
    ( partition by DepartmentId order by Salary desc
      groups between 1 following and unbounded following)
  ntile(10) over
    ( partition by DepartmentId order by Salary desc
      rows between 1 preceding and current row)
  ntile(10) over
    ( partition by DepartmentId order by Salary desc
      rows between unbounded preceding and (upto*2) preceding)
  ntile(10) over
    ( partition by DepartmentId order by Salary desc
      range between current row and (upto*2) following)
```

Default window. For an empty window specification, use `<~` with nothing following:

delightql
```
  employee(*)
    |> +(  row_number:( <~ ) as row_number )
```

SQL
```
select
  *,
  row_number() over () as row_number
from employee;
```

2.6.8. Scalar Subquery

Scalar subqueries return a single value (one row, one column) usable anywhere a column is valid. Delightql transforms a relation into a scalar subquery by postfixing its name with `:` and using interior notation.

Uncorrelated. The subquery is independent of the outer query:

delightql
```
employee(*)
    |> (FirstName,
        LastName,
        Salary,
        employee:( ~> avg:(Salary)) as AvgSalary)
```

SQL
```
select
  FirstName,
  LastName,
  Salary,
  (select avg(Salary) from employee) as AvgSalary
from employee;
```

The F-COLON sigil `:` after the relation name signals a scalar subquery. The interior notation–here `~> avg:(Salary)` – must produce exactly one row and one column.

Correlated. The subquery references values from the outer query. Use an explicit condition to correlate on a column:

delightql

```
employee(*) as e
    |> (FirstName,
        LastName,
        Salary,
        employee:( ~> avg:(Salary)) as AvgSalary,
        employee:( , DepartmentName = e.DepartmentName ~> avg:
(Salary)) as AvgSalaryInDept)
```

SQL

```
select
  FirstName,
  LastName,
  Salary,
  (select avg(Salary) from employee) as AvgSalary,
  (select avg(Salary) from employee
      where DepartmentName = e.DepartmentName) as
AvgSalaryInDept
from employee e;
```

2.6.9. Context-Aware Functions

A context-aware function closes over columns from its invocation context rather than receiving them as explicit parameters.

delightql

```
employee(*)
  |> ( cost_of_living:(..) as col_adjusted_salary)
```

The **UP-CONTEXT** sigil `..` signals that the function references columns from the surrounding scope. It is required – a reminder that the function is never truly nullary.

Context-aware functions are defined with `..` in their signature:

delightql
```
// only works within the context of a
//  relation that has 'City' and 'Salary' columns

cost_of_living:( .. ) :-
  _:(  City in ("San Francisco";"Boston";"New York")
          -> Salary*0.8;
      City in ("Amarillo"; "Knoxville")
          -> Salary*1.45;
      _ -> Salary)
```

This function can be invoked on any relation with `City` and `Salary` columns – the free variables in its body. These columns are bound at the call site, not passed explicitly.

Context-aware functions have no SQL counterpart; they are expanded inline during transpilation.

2.6.10. Boolean Expressions as Columns

Predicates – what delightql calls sigma clauses – can appear in column position, returning boolean values. [22]

22 Some SQL dialects lack a boolean type; these transpile to 1 and 0.

delightql
```
employee(*)
    |> +( DepartmentCity="San Francisco"
            and Title!="Engineer"
                AS san_fran_engineer,
          DepartmentCity="San Francisco"
                AS san_fran,
          Salary > 150000
            or BonusPercentage > 200
                AS well_compensated,
          Title!="Engineer"
                AS is_engineer)
```

SQL
```
  select
    *,
    DepartmentCity = 'San Francisco' and Title != 'Engineer' as
san_fran_engineer,
    DepartmentCity = 'San Francisco' as san_fran,
    Salary > 150000 or BonusPercentage > 200 as well_compensated,
    Title != 'Engineer' as is_engineer
  from employee;
```

Compound predicates must use keywords (`and`, `or`) rather than sigils (`,` , `;`) when appearing as column expressions.

Existence tests. Semi-joins and anti-joins also return booleans when used in column position:

delightql

```
employee(*)
 |> +( +department(,
         department.DepartmentId
          =employee.DepartmentId),
      \+ department(,
         department.DepartmentId
          =employee.DepartmentId),
      +between(Salary,50000,75000))
```

SQL

```
select
  *,
  --
  exists (select 1 from department
    where department.DepartmentId=employee.DepartmentId),
  --
  not exists (select 1 from department
    where department.DepartmentId=employee.DepartmentId),
  --
  Salary between 50000 and 75000
from employee;
```

2.6.11. Compound Data Constructors

The enclyphs `{ }` and `[ ]` construct compound data–records and tuples. They are functions, though they look like syntax. Their behavior depends on context:

Position	`{ }`	`[ ]`
Scalar (non-reduction)	interior record	interior tuple
Aggregate (after ~>)	table of records	table of tuples

Table 8: Compound data constructor behavior by position

delightql

```
-- scalar constructors
employee(*) |>
  ( [LastName,FirstName] as interior_tuple )
employee(*) |>
  ( {LastName,FirstName} as interior_record )

-- aggregate constructors
employee(*)
  |> ( Department
        ~>
      [LastName,FirstName] as table_of_tuples )
employee(*)
  |> ( Department
        ~>
      { LastName,FirstName } as table_of_records )
```

These constructors transpile to JSON in most SQL dialects. [23] But the concept is not about JSON per se but about nested structure.

23 SQLite and Postgres both provide JSON as a data type with supporting functions. See SQLite JSON1.

> The compound data types introduced here provide groundwork for pivots, melts, and tree-grouping (covered later). Programmers needing arbitrary JSON manipulation can call SQL's JSON functions directly:
>
> `json_array:(last_name, first_name)`.

2.6.11.1. Scalar Interior Record

The INTERIOR-RECORD enclyph `{ }` creates a nested row addressable by name:

delightql
```
employee(*)
  |> (Department , { LastName,FirstName } as name  )
```

Department	name
Accounting	{"FirstName":"Erhard","LastName":"Moorrud"}
Product Management	{"FirstName":"Anson","LastName":"Woodall"}

Table 9: Scalar interior record result

Column names become keys. To specify different keys:

delightql
```
employee(*)
  |> (Department ,
      { "FirstName": FirstName ,
        "LastName" : LastName} as name  )
```

Access nested fields with JSON-access notation (see next section).

delightql
```
employee(*)
  |> (Department ,
      { "FirstName": FirstName ,
        "LastName" : LastName} as name  )
  |> ( Department, name:{.FirstName})
```

SQL

```sql
with
    _cpr0 as (
        select
          Department,
          json_object('FirstName',FirstName,
                      'LastName' ,LastName) as name
        from employee)
    select
        Department,
        name ->> "$.FirstName" as FirstName
    from _cpr0;
```

2.6.11.2. Aggregate Interior Record

In a reduction position, `{ }` collects multiple records into a table:

delightql

```
employee(*)
  |> %(Department ~> { LastName,FirstName } as name )
```

Department	name
Accounting	[{"LastName":"Moorrud","FirstName":"Erhard"}, {"LastName":"Cowwell","FirstName":"Orlando"}, {"LastName":"Tuley","FirstName":"Hanan"}, {"LastName":"Unstead","FirstName":"Gretchen"}]
Business Development	[{"LastName":"Marcone","FirstName":"Dinnie"}, {"LastName":"Tuffell","FirstName":"Mathias"}, {"LastName":"Harbord","FirstName":"Venita"}, {"LastName":"Hinstock","FirstName":"Ashli"}]

Table 10: Aggregate interior record result – grouped by Department

The outer `[ ]` in the JSON represents multiplicity – a list of rows. The interior table has a uniform schema of named columns represented as objects.

2.6.11.3. Scalar Interior Tuple

The **INTERIOR-TUPLE** enclyph `[ ]` creates a nested row addressable by position:

delightql

```
employee(*)
  |> (Department , [LastName,FirstName] as name )
```

Department	name
Accounting	["Erhard","Moorrud"]
Product Management	["Anson","Woodall"]

Table 11: Scalar interior tuple result

Access elements by index:

```delightql
employee(*)
  |> (Department , [LastName,FirstName] as name )
  |> ( Department, name:[1] as first_name)
```

2.6.11.4. Aggregate Interior Tuple

In a reduction position, `[ ]` collects multiple tuples into a table:

```delightql
employee(*)
  |> %(Department ~> [ LastName,FirstName ] as name )
```

Department	name
Accounting	[["Erhard","Moorrud"], ["Orlando","Cowwell"], ["Hanan","Tuley"], ["Gretchen","Unstead"]]
Business Development	[["Dinnie","Marcone"], ["Mathias","Tuffell"], ["Venita","Harbord"], ["Ashli","Hinstock"]]

Table 12: Aggregate interior tuple result – grouped by Department

JSON's `[ ]` does double duty here: the outer brackets indicate multiple rows; the inner brackets indicate tuples. This is a syntactic limitation of JSON, not a semantic ambiguity. [24]

24 If JSON had a distinct tuple syntax – perhaps parentheses – this overloading would not exist.

2.6.11.5. Nesting

The power of these constructors emerges when nested:

```delightql
employee(*)
  ~>  {  Title ,
           "people_by_state":
            ~>{ State ,
               "people" : ~>{FirstName, LastName} } }
                 as people_by_state_within_title
```

This tree-structured output is covered in detail in the **Tree Groups** section.

2.6.12. Compound Data Pathing

Once compound data has been constructed, access its contents via pathing syntax.

Array access. Name the column, followed by a colon, the `[ ]` enclyph, and a 0-indexed position:

```delightql
employee(*)
  |> (Department , [LastName,FirstName] as name )
  |> ( Department, name:[0] as first_name)
```

Record access. Name the column, followed by a colon, the `{ }` enclyph, and a dot-prefixed key:

```delightql
employee(*)
  |> (Department ,
      { "FirstName": FirstName ,
        "LastName" : LastName} as name  )
  |> ( Department, name:{.FirstName})
```

Nested access. Chain steps with dots to descend into nested structures:

```
users(*)
  |> ( {last_name, "hardcoded" : [ 1,'x'] } as packet)
  |> ( packet:{.hardcoded.1})
// returns 'x' for as many records as there are users
```

```delightql
_(x @ [ 1 , 2 , {"hardcoded" : {"deeper": [ 2 , 3]}}])
as named_anon_table
  |> (x:[2.hardcoded.deeper.0])
```

Uniform dot notation. Unlike most languages, delightql does not alternate between `.key` and `[index]` when pathing. All steps – whether into a record or an array – use dot separation: `key.1.nested.0` rather than `key[1].nested[0]`. The enclyph at the start (`{ }` or `[ ]`) establishes the top-level type; thereafter, dots suffice.

2.7. ADDRESSING COLUMNS BY INDEX

Named columns are preferred for clarity, but some schemas resist naming–wide CSVs, auto-generated headers, legacy tables with hundreds of columns. For these, delightql provides index notation.

delightql
```
employee(*)
  |> ( |1|, |2|, |3| )
```

SQL
```
select
    EmployeeId, -- at position 1
    LastName,   -- at position 2
    FirstName   -- at position 3
from employee;
```

The INDEX enclyph `|  |` encloses an integer literal (no expressions). Indices are 1-based; negative indices count from the end.

delightql
```
employee(*)
  |> (|-3|, |-2|, |-1|)
```

SQL
```
SELECT
  Phone,  -- position -3
  Fax,    -- position -2
  Email   -- position -1
FROM employee;
```

> Indexing conventions. Column indices are 1-based, following SQL's ORDER BY 1 convention. Array pathing is 0-based, following JSON/JavaScript convention. The first column is `|1|` the first array element is `[0]`.

2.7.1. Column Ranges

A COLUMN RANGE `|start:end|` selects a contiguous slice of columns by position. Both bounds are inclusive and 1-based.

delightql
```
users(*)
  |> ( |1:3| )
```

```sql
SELECT id, first_name, last_name
FROM users;
```

Either bound may be omitted. An open start means “from the first column”; an open end means “through the last column”:

```delightql
users(*)
  |> ( |:3| )           -- first three columns
```

```sql
SELECT id, first_name, last_name
FROM users;
```

```delightql
users(*)
  |> ( |5:| )           -- fifth column onward
```

```sql
SELECT age, status, country, created_at, last_login,
balance
FROM users;
```

Negative indices count from the end, following the same convention as single ordinals:

```delightql
users(*)
  |> ( |-3:-1| )        -- last three columns
```

```sql
SELECT created_at, last_login, balance
FROM users;
```

```delightql
users(*)
  |> ( |:-2| )          -- all but the last column
```

```sql
SELECT id, first_name, last_name, email, age, status,
country, created_at, last_login
FROM users;
```

Ranges can be scoped to a table alias, just like single ordinals:

```delightql
users(*) as u
  |> ( u|1:3|, u|5:7| )
```

```sql
SELECT id, first_name, last_name, age, status, country
FROM users AS u;
```

Ranges compose with other operators. For example, EMBED-MAP can apply a function across a range of columns:

```delightql
users(*)
  |> +$(:( @ + 100) as :"{@}_offset")(|2:5|)
```

Syntax	Meaning
`|1:3|`	Columns 1 through 3
`|5:|`	Column 5 through last
`|:3|`	First through column 3
`|-3:-1|`	Third-to-last through last
`|:-2|`	First through second-to-last
`u|1:3|`	Columns 1–3 of alias `u`

Table 13: Column range syntax summary

When ranges break down. The same caveats as single ordinals apply: schema changes silently shift what a range covers. Prefer named columns for stable queries; reserve ranges for exploration and hostile schemas.

Index notation works with **PROJECT-OUT**, **RENAME-COVER**, **MAP-COVER**, **GROUP-MODULO**, and other operators:

```delightql
employee(*)
  |> -( |1|, |2| , |-2| )
```

Scoped Index Notation

In joins, indices can be scoped to a table alias:

```delightql
employee(*) as e,
  department(*) as d, d.DepartmentName=e.DepartmentName
  |> (  |14| as email,
        e|1| as EmployeeId,
        d|-4| as DepartmentName)
```

Unscoped indices refer to the total column order across all joined tables. The following addressing schemes are available:

Scheme	Example	Meaning
Total	`|14|`	14th column overall
Total reverse	`|-5|`	5th from end overall
Scoped	`e|1|`	1st column of `e`
Scoped reverse	`e|-1|`	Last column of `e`
Named	`e.Email`	By name

Table 14: Index addressing schemes

When index notation breaks down. Total indexing across joins depends on column counts and join order. For this reason, it's probably wise to reserve index notation for exploration, and managing hostile schemas.

2.7.2. Reposition Operator

The REPOSITION operator `*[column as position]` moves columns to specific positions without removing any columns.

delightql
```
users(*) |> *[email as 1]
```

SQL
```
SELECT email, id, first_name, last_name, age FROM users;
-- Before: (id, first_name, last_name, email, age)
-- After:  (email, id, first_name, last_name, age)
```

The column `email` moves to position 1; all other columns shift to accommodate.

2.7.2.1. Positive and Negative Positions

Positions are 1-indexed. Negative positions count from the end:

Position	Meaning
1	First
2	Second
-1	Last
-2	Second-to-last

Table 15: Position meanings for the reposition operator

delightql
```
users(*) |> *[id as -1]
```

Moves `id` to the last position:

```
Before: (id, first_name, last_name, email, age)
After:  (first_name, last_name, email, age, id)
```

2.7.2.2. Multiple Repositions

Multiple columns can be repositioned in a single operation:

delightql
```
users(*) |> *[email as 1, age as 2]
```

```
Before: (id, first_name, last_name, email, age)
After:  (email, age, id, first_name, last_name)
```

Columns are placed in the order specified; remaining columns fill the gaps.

2.8. COMMON EXPRESSIONS

Delightql has two forms of common expression: the traditional common table expression, and a delightql-specific common function expression.

2.8.1. Common Table Expressions

Create a common table expression (**CTE**) by naming a functor with a glob, followed by a `:`, also known as **SHADOW-NECK**, followed by the query that is assigned to that name. This syntax is called pre-labeling.

Once, a common table expression is defined, it is sufficient to query from that as if it were a table.

delightql

```
adults(*) : users(*), age > 30
adults(*)
```

SQL

```
WITH "adults" AS (
  SELECT *
  FROM "users"
  WHERE "age" > 30
)
SELECT *
FROM "adults";
```

An alternate syntax, called post-labeling, allows the CTE to be named after the query by postfixing a valid query with the **SHADOW-NECK** `:` and a simple identifier:

delightql

```
users(*), age > 30 : adults
adults(*)
```

These syntaxes may be intermixed:

delightql

```
us_users(*): users(*), country = 'USA'
orders(*), status = 'completed' : completed_orders
us_users(*), completed_orders(*)
```

SQL

```sql
WITH "us_users" AS (
  SELECT *
  FROM "users"
  WHERE "country" IS NOT DISTINCT FROM 'USA'
),
"completed_orders" AS (
  SELECT *
  FROM "orders"
  WHERE "status" IS NOT DISTINCT FROM 'completed'
)
SELECT *
FROM "us_users"
CROSS JOIN "completed_orders";
```

2.8.2. Common Function Expressions

Create common function expressions (**CFEs**) – functions whose name is created for the duration of the query – by pre-labeling with a functional functor.[25] The **SHADOW-NECK** separates the functional functor on the left from any valid domain expression on the right. CFEs may **only** be created by pre-labeling.

25 A functional functor is a functor with a colon separating the identifier from the opening parenthesis.

delightql

```
enweirden:(age) :
  age /-> :(@ - 18) /-> max:(0) /-> min:(100)

users(*) |> (enweirden:(age) as silly, age)
```

SQL

```sql
SELECT
  min(max("age" - 18, 0), 100) AS "silly",
  "age" AS "age"
FROM "users";
```

CTEs and CFEs may be intermixed:

delightql

```
double:(x) : (x * 2)
users(*), age > 25 : adults
triple:(y) : (y * 3)
young_adults(*): adults(*), age < 40
young_adults(*)
  |> ( id,
       first_name,
       age,
       double:(age) as doubled,
       age /-> double:() /-> double:() as quadrupled,
       triple:(age) as tripled,
       double:(triple:(age)) as sextupled)
```

SQL
```sql
WITH adults AS (
    SELECT
        *
    FROM users
    WHERE age > 25
),
young_adults AS (
    SELECT
        *
    FROM adults
    WHERE age < 40
)
SELECT
    id,
    first_name,
    age,
    (age * 2) AS doubled,
    ((age * 2) * 2) AS quadrupled,
    (age * 3) AS tripled,
    ((age * 3) * 2) AS sextupled
FROM
    young_adults;
```

2.8.3. Recursive Common Table Expressions

A common table expression becomes recursive when one of its defining clauses references the CTE being defined. Delightql detects this self-reference and emits WITH RECURSIVE.

Sequence generation:

delightql
```
_(n @ 1) : nums
nums(*), n < 100 |> (n + 1 as n) : nums
nums(*) ~> sum:(n)
```

SQL
```sql
WITH RECURSIVE nums(n) AS (
    SELECT 1 AS n
    UNION ALL
    SELECT n + 1 FROM nums WHERE n < 100
)
SELECT sum(n) FROM nums;
```

The first clause seeds the CTE with 1. The second clause references nums and increments until the condition fails. This is the standard pattern: base case, then recursive case with termination condition.

Multiple clauses accumulate:

Non-recursive CTEs can have multiple clauses that combine via UNION ALL:

```delightql
users_2022(*) |> (first_name, last_name) : names
users_2023(*) |> (first_name, last_name) : names
users_2024(*) |> (first_name, last_name) : names
names(*)
```

When any clause references the CTE name, the entire CTE becomes recursive:

```delightql
_(x @ 1) : nums
_(x @ 100) : nums
nums(*), x < 200 |> (x + 1 as x) : nums
nums(*)
```

Here, two anchor clauses (starting at 1 and 100) seed the recursion. Both sequences grow until reaching 200.

2.9. WHERE

Selection (σ in Codd's relational algebra, `WHERE` in SQL) filters rows without changing schema. [26]

Delightql uses the comma (conjunction) to attach predicates to relations. This is the same syntax as joins and comes directly from Prolog.

26 SQL's use of "select" for projection is unfortunate – Codd used "select" for row filtering. Delightql follows Codd's terminology.

2.9.1. Domain Predicates

```delightql
employee(*), Salary > 50000
```

```sql
select * from employee where Salary > 50000;
```

Multiple predicates conjoin naturally:

```delightql
  employee(*), Salary > 50000,
    trim:(lower:(Department))="engineering"
```

```sql
select * from employee
  where Salary > 50000
    and trim(lower(Department))
      IS NOT DISTINCT FROM 'engineering';
```

Scope restricts commutativity. Predicates can only reference columns already in scope. This is invalid:

delightql
```
// WONT WORK because Salary is not yet in scope
  Salary > 50000,
    trim:(lower:(Department))="engineering",
    employee(*)
```

But once columns are in scope, predicates may be re-ordered:

delightql
```
employee(*),
  Salary > 50000,
  trim:(lower:(Department))="engineering"

// commutativity allowed when all LVars are in scope

employee(*),
  trim:(lower:(Department))="engineering",
  Salary > 50000
```

Null-safe vs Null-dangerous equality. Delightql reserves the `=` sigil for the SQL comparison operator `IS NOT DISTINCT FROM`. To use the traditional (dangerous) equality in SQL, use delightql's `==` sigil.

delightql
```
employee(*), Salary > 50000,
    trim:(lower:(Department))="engineering",
    LastName=="John"
```

SQL
```
select * from employee
  where Salary > 50000
    and trim(lower(Department))
      IS NOT DISTINCT FROM 'engineering'
    and LastName='John';
```

> **Three-Valued Logic**
>
> Null has been with databases since the very beginning and so has the debate about its semantics and danger.
>
> SQL provides 'good enough' semantics for its usage in the set operations of distinct, grouping, union and intersect, but it can be a foot-gun in other circumstances.
>
> The simplest display of its behavior below:

```sql
select
    null=null,
    null is null,
    null is not null,
    1=null,
    1 is null,
    1 is not null,
    1 in (select null union all select 2),
    1 not in (select null union select 2),
    1 in (select null union all select 1),
    1 not in (select null union select 1)
;
```

shows many odd results

```
null=null                                =  null
null is null                             =  1
null is not null                         =  0
1=null                                   =  null
1 is null                                =  0
1 is not null                            =  1
1 in (select null union all select 2)    =  null
1 not in (select null union select 2)    =  null
1 in (select null union all select 1)    =  1
1 not in (select null union select 1)    =  0
```

Sigil	Name	SQL Equivalent
=	NULL-SAFE-GROUND-EQ	IS NOT DISTINCT FROM
==	TRAD-GROUND-EQ	= or ==
>	GROUND-GT	>
<	GROUND-LT	<
>=	GROUND-GTE	>=
<=	GROUND-LTE	<=
!=	NULL-SAFE-NOT-EQ	IS DISTINCT FROM
!==	TRAD-NOT-EQ	!=

Table 16: Infix domain predicates

The join-position exception.

The table above describes equality in filter position – conditions referencing columns from zero or one rela-

> tion. In join position – conditions correlating columns from two or more relations – both = and == compile to SQL =.
>
> This is the safe default for joins as `IS NOT DISTINCT FROM` in a join condition would treat NULL as a matchable value. The NULL-by-NULL cartesian product is almost never intended and can explode cardinality.
>
> Joins establish structural correspondence – "these rows belong together." NULL means absence, and absence does not make a correspondence. Filters test value equality, where null-safety matters because rows should not silently disappear.
>
> The compiler already distinguishes these contexts: a condition referencing two relations becomes an ON clause; a condition referencing one relation becomes a WHERE clause. The equality semantics ride on this same distinction.
>
> To opt into null-matching joins (the rare case where NULL-to-NULL correspondence is desired), use a danger gate:

delightql
```
employee(*) as e (~~danger://dql/cardinality/
nulljoin ON~~),
  department(*) as d,
  e.DepartmentId = d.DepartmentId
```

2.9.2. Argumentative Grounding

When using argumentative functor notation, a ground term in argument position induces selection:

delightql
```
stock_ownership(1,stock_id,stock_name,quantity)
```

SQL
```
select
  stock_id,
  stock_name,
  quantity
from stock_ownership where people_id IS NOT DISTINCT
FROM 1;
```

All argumentative grounding uses null-safe equality.

The grounded column (`people_id  IS NOT DISTINCT FROM 1`) filters rows and is excluded from projection. Multiple grounds compound:

delightql
```
stock_ownership(people_id,5,stock_name,120)
```

SQL
```
SELECT people_id, stock_name
FROM stock_ownership
WHERE
  stock_id IS NOT DISTINCT FROM 5
  AND quantity IS NOT DISTINCT FROM 120;
```

Any domain expression that reduces to a ground term may also be used in argumentative position:

delightql
```
stock_ownership(people_id,(4 + 1),upper:("msft"),120)
```

SQL
```
select
  people_id
from stock_ownership where stock_id IS NOT DISTINCT FROM
(4+1) and quantity IS NOT DISTINCT FROM 120 and
stock_name IS NOT DISTINCT FROM upper('msft');
```

The Prolog heritage is evident in this syntax and extends to joins – covered in a later section.

2.9.3. Semi-Joins and Anti-Joins

Semi-joins (∃ or ⋉) and anti-joins (∄ or ▷) test for existence without contributing columns. They ask "can you prove this?" rather than "give me this data."

The **PROVE** sigil `+` prefixes a semi-join:

delightql
```
employee(*) as e, +fired_employees(, e.EmployeeId=id)
```

SQL
```
SELECT *
FROM employee AS e
WHERE
  EXISTS (
    SELECT 1
    FROM fired_employees
    WHERE
      id IS NOT DISTINCT FROM e.EmployeeId
  );
```

The DISPROVE sigil `\+` prefixes an anti-join: [27]

delightql
```
employee(*) as e, \+ fired_employees(,
e.EmployeeId=f.id)
```

27 This syntax comes directly from Prolog's negation-as-failure.

SQL
```
select
  *
from employee e
  where not exists (select 1 from fired_employees
                      where id IS NOT DISTINCT FROM
e.EmployeeId);
```

The join condition(s) appears inside the parentheses – this is called interior notation. The relation is tested for provability, not joined for data.

2.9.4. The `in` Predicate

delightql
```
employee(*), +_(State@"MA";"TX";"AK";"AR")
```

Syntactic sugar provides the familiar form:

delightql
```
employee(*), State in ("MA";"TX";"AK";"AR")
```

Both transpile to:

SQL
```
select
  *
from employee where State in ('MA','TX','AK','AR');
```

The unsugared form generalizes to multi-column comparisons:

delightql
```
employee(*), +_( State, Department @
                 "MA","Engineering";
                 "TX","Engineering";
                 "CA","Sales")
```

SQL
```
SELECT *
FROM employee
WHERE
  ('MA' IS NOT DISTINCT FROM State
  AND 'Engineering' IS NOT DISTINCT FROM Department)
  OR ('TX' IS NOT DISTINCT FROM State
  AND 'Engineering' IS NOT DISTINCT FROM Department)
  OR ('CA' IS NOT DISTINCT FROM State
  AND 'Sales' IS NOT DISTINCT FROM Department);
```

2.9.5. Relational `in`

The literal form tests membership in a fixed list. The relational form tests membership in the result of a query – SQL's `IN (SELECT ...)`.

The right-hand side is any DQL relation (a table access, a pipe chain, or an anonymous table):

delightql
```
employee(*), DepartmentId in department(|>
(DepartmentId))
```

SQL
```
SELECT * FROM employee
  WHERE DepartmentId IN (SELECT DepartmentId FROM
department);
```

When the relation already has exactly one column, projection is unnecessary:

delightql
```
employee(*), State in valid_states(*)
```

SQL
```
SELECT * FROM employee
  WHERE State IN (SELECT State FROM valid_states);
```

2.9.5.1. Tuple relational `in`

Multi-column matching extends the tuple `in` syntax (`(x,y) in (1,2;3,4)`) to relations. The relation must produce exactly as many columns as the left-hand tuple:

delightql
```
employee(*), (State, Department) in valid_combos(|>
(State, Department))
```

SQL
```
SELECT * FROM employee
  WHERE (State, Department) IN
    (SELECT State, Department FROM valid_combos);
```

2.9.5.2. Negation: `not in`

delightql
```
employee(*), DepartmentId not in terminated_depts(|>
(DepartmentId))
```

SQL
```
SELECT * FROM employee
  WHERE DepartmentId NOT IN (SELECT DepartmentId FROM
terminated_depts);
```

> **Arity rule**
>
> The relation must produce exactly as many columns as the left side has elements – one for a scalar, N for an N-tuple. A mismatch is a compile-time error.

> **Relation to semi-joins**
>
> Relational `in` is syntactic sugar over the semi-join notation introduced above. `col in R(|> (c))` desugars to `+R(, col = c)`; `col not in R(|> (c))` desugars to `\+R(, col = c)`.

2.9.6. Inverted `In`

The anonymous semi-join syntax permits an inversion – ground the header, vary the rows:

delightql
```
people(*),
    +_("MA" @
      birth_state;
      death_state;
      work_state;
      marriage_state)
```

SQL
```
select
  *
from people
  where birth_state IS NOT DISTINCT FROM 'MA'
    or death_state IS NOT DISTINCT FROM 'MA'
    or work_state IS NOT DISTINCT FROM 'MA'
    or marriage_state IS NOT DISTINCT FROM 'MA';
```

This asks: "does 'MA' appear in any of these columns?" The columns become the rows of the anonymous table; the constant becomes the match target.

> **SQL supports Inverted In**
>
> Though it might be a revelation to some – including the author! – the inverted in is standard SQL and is fully supported by all dialects:
>
> SQL
> ```
> select
>   *
> from people
>   where 'MA' in
> (birth_state,death_state,work_state,marriage_state);
> ```

Similarly, to test if one column equals any of several others:

delightql
```
people(*), +_(birth_state @ death_state; work_state;
marriage_state)
```

SQL
```
select
  *
from people
  where birth_state IS NOT DISTINCT FROM death_state
    or birth_state IS NOT DISTINCT FROM work_state
    or birth_state IS NOT DISTINCT FROM marriage_state;
```

2.9.7. Sigma Predicates

Predicates can be defined and reused. A sigma predicate is a rule that expands into selection criteria: [28]

28 Defining sigma predicates is covered in DDL.

delightql
```
no_data("NA";"N/A";"UNKNOWN")

empty(column) :- null=column
empty(column) :- trim:(column)==""
empty(column) :- +no_data(upper:(column))
```

Use with semi-join or anti-join syntax:[29]

29 Delightql applies De Morgan's laws, distributing negation across disjunctive clauses.

delightql
```
employee(*),
  \+empty(LastName),
  \+empty(FirstName)
```

SQL
```
SELECT *
FROM employee
WHERE
  LastName IS NOT null
  AND '' != trim(LastName)
  AND upper(LastName) NOT IN (
    'NA',
    'N/ A',
    'UNKNOWN'
  )
  AND (FirstName IS NOT null
  AND '' != trim(FirstName)
  AND upper(FirstName) NOT IN (
    'NA',
    'N/ A',
    'UNKNOWN'
  ));
```

2.9.7.1. *Like* and Between

SQL's LIKE and BETWEEN have special syntax. Delightql maps functor notation to these constructs:

delightql
```
employee(*), +like(Email,"%.com"), \
+between(Salary,10000,100000)
```

The above delightql transpiles to the following Sql.

SQL
```
select
  *
from employee
  where
    Email like '%.com' and
    Salary not between 10000 and 100000;
```

2.9.7.2. Disjunction

Two syntaxes express OR:

Keyword form (recommended). The or keyword binds predicates within a sigma clause:

delightql
```
employee(*)
  , trim:(lower:(Department)) = "executive"
        or Salary > 120000
  , Title != "Engineer"
  |> %( DepartmentCity
          ~>
        count:(*) as employee_count,
        avg:(Salary) )
```

Sigil form. The **SEMI-OR** sigil ; requires parentheses to capture scope:

delightql
```
employee(*)
  , (trim:(lower:(Department)) = "executive"
        ; Salary > 120000 )
  , Title != "Engineer"
  |> %( DepartmentCity
          ~>
        count:(*) as employee_count,
        avg:(Salary) )
```

Prefer the keyword form – it reads more clearly and avoids parenthesis errors. See "Precedence and Scoping" for details.

2.10. JOIN

Joins extend a relation's schema by combining columns from multiple sources. Every join is a filtered cross product – the join condition determines which pairings survive.

Delightql evaluates joins left to right. Each table must be in scope before its columns can be referenced.

2.10.1. Cross Join

delightql
```
employee(*), department(*)
```

SQL
```
SELECT * FROM employee CROSS JOIN department;
```

Two relations joined with no condition produce a Cartesian product. The resulting cardinality is the product of both input cardinalities. This is rarely intended.

2.10.2. Inner Join

delightql
```
employee(*), department(*), employee.DepartmentId =
department.DepartmentId
```

SQL
```
SELECT * FROM employee
  JOIN department ON employee.DepartmentId =
department.DepartmentId;
```

The join condition follows the tables it correlates. Multiple conditions conjoin naturally:

delightql
```
employee(*), department(*),
  employee.DepartmentId = department.DepartmentId,
  employee.Location = department.Location
```

Scope is left to right. This is an error:

delightql
```
// INVALID: department not yet in scope
employee(*), department.DepartmentId =
employee.DepartmentId, department(*)
```

2.10.3. `USING` Shorthand

The `.(cols)` operator specifies USING columns:

delightql
```
employee(*), department(*.(DepartmentId))
```

SQL
```
SELECT * FROM employee JOIN department USING
(DepartmentId);
```

Multiple columns are comma-separated:

delightql
```
employee(*), department(*.(DepartmentId, LocationId))
```

SQL
```
SELECT * FROM employee JOIN department USING
(DepartmentId, LocationId);
```

`USING` and explicit `ON` differ operationally: `USING` retains one copy of the matched column; `ON` retains both.

`USING` may combine with explicit conditions:

delightql
```
employee(*), department(*.(DepartmentId)),
employee.StartDate > department.Founded
```

2.10.4. Multi-Table Joins

Joins chain left to right. Each table enters scope upon appearance:

delightql
```
employee(*),
  department(*.(DepartmentId)),
  location(*.(LocationId)),
  employee.StartDate > "2020-01-01"
```

SQL
```
SELECT * FROM employee
  JOIN department USING (DepartmentId)
  JOIN location USING (LocationId)
WHERE employee.StartDate > '2020-01-01';
```

After the third table, columns from all three are in scope.

2.10.5. Self-Join

Aliases distinguish multiple references to the same table:

delightql
```
employee(*) as e, employee(*) as mgr, e.ManagerId =
mgr.Id
  |> (e.Name as Employee, mgr.Name as Manager)
```

SQL
```
SELECT e.Name AS Employee, mgr.Name AS Manager
FROM employee e
  JOIN employee mgr ON e.ManagerId = mgr.Id;
```

2.10.6. Argumentative Join

Shared identifiers across functors induce join conditions – Prolog-style unification:

```delightql
employee(Name, Department), department(Department,
location)
```

```SQL
SELECT employee.Name, employee.Department,
department.location
FROM employee
  JOIN department ON employee.Department =
department.Department;
```

The variable `Department` appears in both functors, unifying the columns.

Multi-table example:

```delightql
people(people_id, _, last_name),
  stock_ownership(people_id, stock_id, quantity),
  stocks(stock_id, stock_name),
  quantity < 200
  |> (last_name, stock_name)
```

Argumentative joins are idiomatic in Prolog. Delightql supports them but recommends `.(cols)` or explicit conditions for wide tables where positional notation becomes error-prone.

2.10.7. Outer Joins

The OUTER-IND sigil `?` marks a relation as optional – it may contribute nulls when no match exists.

Left outer (right table optional):

```delightql
employee(*), department?(*.(DepartmentId))
```

```SQL
SELECT * FROM employee LEFT OUTER JOIN department USING
(DepartmentId);
```

Right outer (left table optional):

```delightql
employee?(*), department(*.(DepartmentId))
```

Full outer (either optional):

```delightql
employee?(*), department?(*.(DepartmentId))
```

Outer joins work with explicit conditions:

```delightql
employee(*), department?(*), employee.DepartmentId =
department.DepartmentId
```

```sql
SELECT * FROM employee
  LEFT OUTER JOIN department ON employee.DepartmentId =
department.DepartmentId;
```

2.10.7.1. ON vs WHERE Inference

For inner joins, the placement of conditions in `ON` versus `WHERE` is semantically equivalent. For outer joins, it differs: `ON` conditions govern the match while preserving nulls; `WHERE` conditions filter the result and eliminate nulls.

Delightql infers placement from column references:

- **Condition references multiple tables** → `ON`
- **Condition references one table** → `WHERE`

```delightql
employee(*), department?(*),
  employee.DepartmentId = department.DepartmentId,   --
two tables → ON
  department.Status = "active"                        --
one table → WHERE
```

```sql
SELECT * FROM employee
  LEFT OUTER JOIN department
    ON employee.DepartmentId = department.DepartmentId
WHERE department.Status = 'active';
```

The multi-table condition (`employee.DepartmentId = department.DepartmentId`) becomes the join's `ON` clause. The single-table condition (`department.Status = 'active'`) becomes a `WHERE` filter – employees with null or inactive departments are excluded.

2.10.8. Semi-Join and Anti-Join

Semi-joins and anti-joins test existence without adding columns – they are predicates, not joins. See **Where**.

2.10.9. Lateral Joins

Correlated subqueries that return multiple columns use interior relation syntax. See **Interior Relations**.

2.10.10. ER-Context Joins

When join relationships are defined via **ER-context-rules** (see DDL), the `&` and `&&` operators provide concise join syntax:

```delightql
under normal:
  users(*) & orders(*)
```

Equivalent to:

```delightql
users(*), orders(*), users.id = orders.user_id
```

The `&` operator performs direct lookup; `&&` finds a path through the ER-graph:

```delightql
under normal: users(*) && items(*)
// Compiler finds: users -> orders -> items
```

ER-context joins compose with all other features – filters, projections, aggregations, additional explicit joins.

For defining ER-rules and contexts, see **DDL: ER-Context Rules**.

2.11. UNIFICATION AND LOGICAL VARIABLES

Delightql inherits from Prolog a simple rule: **identifiers unify when their names match exactly**. To **unify** means to insist on equality and via such a simple semantic we can provide an alternate form to joining and filtering.

Unlike Prolog, however, delightql's identifiers are qualified by their table names.

2.11.1. How Names Are Introduced

The way you access a table determines the names of its columns in scope:

Access Pattern	Columns Introduced
`users(id, name, status, _)`	`id`, `name`, `status`
`users(*)`	`users.id`, `users.name`, `users.status`

Access Pattern	Columns Introduced
`users(*) as u`	`u.id`, `u.name`, `u.status`

Table 17: Columns introduced by access pattern

Argumentative access introduces **unqualified** names – bare identifiers. Wildcard access introduces **qualified** names – prefixed by table name or alias.

This distinction is the source of most unification behavior.

2.11.2. Unification Creates Joins

When the same name appears in multiple places, unification creates a join condition:

```delightql
users(user_id, name, _), orders(order_id, user_id,
total, _)
```

Both introduce `user_id`. Unification produces:

```sql
SELECT users.name, orders.order_id, orders.total
FROM users, orders
WHERE users.user_id = orders.user_id;
```

No explicit join condition is needed here – the shared name insists on it. This is argumentative joining, covered in the Join chapter.

2.11.3. Wildcard Access and Qualification

```delightql
users(*), orders(*)
```

This introduces `users.user_id` and `orders.user_id` – different names. No unification occurs; the result is a cross join.

To join with wildcard access, use explicit conditions:

```delightql
users(*), orders(*), users.user_id = orders.user_id
```

Or use the USING operator `.(cols)`:

```delightql
users(*), orders(*.(user_id))
```

2.11.4. Qualified References in Argumentative Access

Argumentative patterns can reference lvars from other tables:

```delightql
users(*) as u, orders(order_id, u.user_id, total, _)
```

The `u.user_id` in positional access matches the `u.user_id` from `users(*) as u`, creating unification. This mixes styles: wildcard for one table, positional for another, with explicit cross-reference.

A more elaborate example:

```delightql
users(*) as u,
reviews(*) as r,
products(product_id, u.user_id, r.rating, _)
```

Here `products` unifies with `users` on `u.user_id` and with `reviews` on `r.rating` – a three-way join through positional cross-references.

2.11.5. Literals and Constraints

Ground terms in positional access create `WHERE` conditions:

```delightql
users(user_id, name, "active", _)
```

The positional grounding filters rows where the third column equals `"active"`. The column `status` has been unified with the ground value `"active"`.

```sql
SELECT user_id, name FROM users WHERE status = 'active';
```

2.11.6. Self-Unification

The same name repeated in positional access forces equality:

```delightql
users(user_id, name, user_id, _)
```

Columns 1 and 3 both bind to `user_id`. This filters to rows where those columns are equal:

```sql
SELECT user_id, name FROM users WHERE column1 = column3;
```

2.11.7. Anonymous Tables and Unification

Anonymous tables participate in unification through their header names:

```delightql
users(user_id, name, status, _),
_(status @ "active"; "pending"; "suspended")
```

The anonymous table introduces `status`. This matches `status` from users, creating:

```sql
SELECT user_id, name, status
FROM users
WHERE status IN ('active', 'pending', 'suspended');
```

With wildcard access, qualification is required:

```delightql
users(*) as u,
_(u.status @ "active"; "pending"; "suspended")
```

Without the `u.` prefix, no unification occurs – the anonymous table's `status` wouldn't match `u.status`.

2.11.8. Lvars as Data in Anonymous Tables

Anonymous tables can use lvars as data values, not just in headers.

Constraint: An lvar cannot appear both in a header and in the data rows of the same anonymous table.

2.11.8.1. Inverted IN Pattern

```delightql
users(*) as u,
_("happy" @ u.status; u.feelings; u.worldview)
```

Find users where `"happy"` appears in any of these columns:

```sql
SELECT * FROM users u
WHERE 'happy' IN (u.status, u.feelings, u.worldview);
```

Or equivalently:

```sql
SELECT * FROM users u
WHERE u.status = 'happy'
   OR u.feelings = 'happy'
   OR u.worldview = 'happy';
```

The anonymous table's header is a literal (`"happy"`); the data rows are lvars from `users`. This inverts the typical IN pattern.

2.11.8.2. EAV Transformation

```delightql
users(*) as u,
_(attribute, value @
  "name", u.name;
  "email", u.email;
  "status", u.status;
  "created", u.created_at)
```

This is the melt pattern discussed in a later chapter.

2.11.8.3. Row-Wise Correspondence

```delightql
users(*) as u,
orders(*) as o,
_(u.status, o.priority @
  u.feelings, o.urgency;
  u.mood, "high";
  "active", "rush")
```

Each row in the anonymous table represents a valid combination. The result includes only rows where `(u.status, o.priority)` matches one of the specified pairs:

```sql
SELECT *
FROM users u, orders o
WHERE (u.status = u.feelings AND o.priority = o.urgency)
   OR (u.status = u.mood AND o.priority = 'high')
   OR (u.status = 'active' AND o.priority = 'rush');
```

2.11.9. Summary of Unification Rules

Pattern	Names Introduced	Unifies With
`t(a, b, c)`	`a`, `b`, `c`	Any `a`, `b`, `c`
`t(*)`	`t.a`, `t.b`, `t.c`	Only `t.a`, `t.b`, `t.c`
`t(*) as x`	`x.a`, `x.b`, `x.c`	Only `x.a`, `x.b`, `x.c`
`t(x.a, b, _)`	`x.a`, `b`	`x.a` from alias `x`; any `b`
`_("lit" @ v1; v2)`	(none – header is literal)	Filters where `lit` matches `v1` or `v2`

Pattern	Names Introduced	Unifies With
`_(col @ "a"; "b")`	`col`	Any `col`

Table 18: Summary of unification rules

2.12. SET OPERATORS

SQL's set operators **UNION**, **INTERSECT** and **EXCEPT** all operate on union-compatible schemas with ordinality-based matching. This means that to use these operators in SQL you need to arrange an enumeration of columns from each table via position and type only, **and** that the number of columns must be the same.

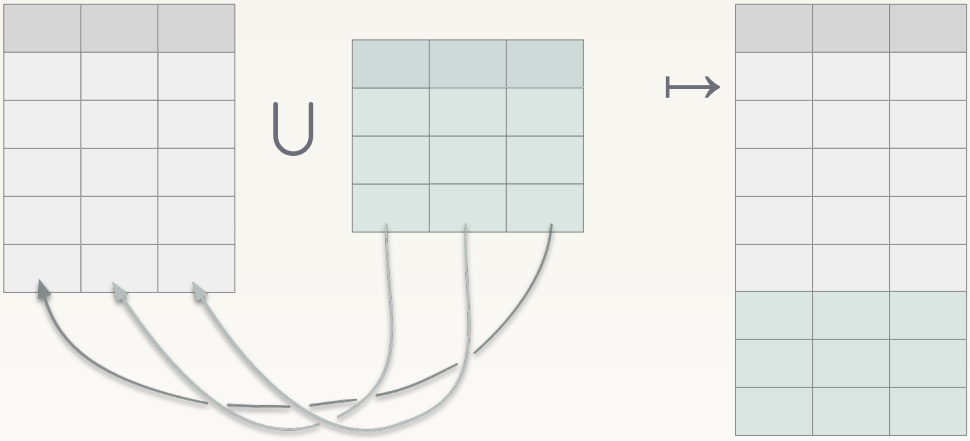


Figure 1: Union Compatability via Ordinal Alignment

It is a somewhat interesting corner of SQL as nowhere else (with the exception of the occasional `group by 2`) does SQL use the ordinality of a relation's columns.

Delightql, of course, supports all of these operators but opens up the door to other functionality by

1. relaxing the same number requirement and permitting ragged unions and intersects
2. having a preference for naming-based access

To make this more concrete, consider delightql's **UNION CORRESPONDING**:

```delightql
users(*) ; users_2024(*)
```

The semicolon sigil `;` of **UNION CORRESPONDING** separates two tables much like a comma would for joining. With this operator columns are matched by their names and a super set of both tables' columns are synthesized.

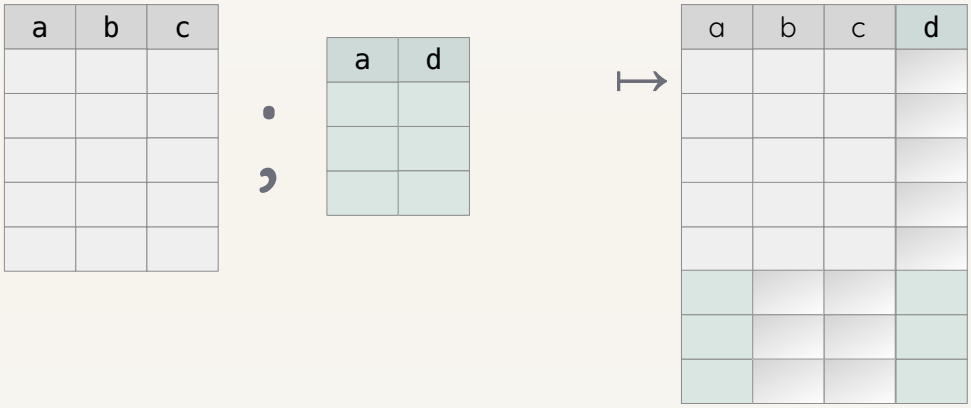


Figure 2: Union Compatability via Name Alignment With OUTER

Delightql re-introduces[30] this CORRESPONDING name-based alignment mode as an alternative to SQL's normal UNION-like ordinal alignment. Delightql prefers name-based alignment but still offers ordinal alignment for backwards compatibility.

30 The SQL standard actually defines a `CORRESPONDING BY` clause (SQL-92 (ISO/IEC 9075:1992)) that can be used with `INTERSECT`, `UNION`, and `EXCEPT`, though, as usual, few actually implemented it. It's even a reserved word.

Delightql's UNION-like operators are the following:

Mode	Sigil	Alignment	Schema requirement
Corresponding	;	By name	Any (NULL-padded)
Smart	|;|	By name	Identical names and same column count
Positional	||	By ordinal	Same column count

Table 19: Set operator alignment modes

2.12.1. Union All Corresponding (;)

Aligns by name, NULL-padding missing columns. Output schema: first relation's columns, then non-overlapping columns from the second.[31]

31 This is closer in definition to OUTER UNION. The few SQLs that implement UNION ALL CORRESPONDING do so by outputting the intersection of the two column sets, instead of the union of the two column sets that delightql favors.

delightql
```
_( a,b,c
   -------
   1,2,3;
   4,5,6)
   ;
_( d,   a,b
  -------
  "foo",10,20;
  "bar",40,50)
```

a	b	c	d
1	2	3	NULL
4	5	6	NULL
10	20	NULL	foo
40	50	NULL	bar

Union All Corresponding is a ragged union.

2.12.2. Smart Union All (`|;|`)

Aligns by name, but requires both relations to have identical column count and names. Unlike SQL's `UNION/UNION-ALL` position is irrelevant. The resulting schema is adopted from the first relation:

delightql
```
employee_2019(*)
  |;|  employee_2018(*)
  |;|  employee_2018(*)
```

SQL

```
SELECT
  EmployeeId, LastName,
  FirstName, Title, ReportsTo,
  BirthDate, HireDate,
  Address, City, State,
  Country, PostalCode, Phone,
  Fax, Email
FROM employee_2019
UNION ALL
SELECT
  EmployeeId, LastName,
  FirstName, Title, ReportsTo,
  BirthDate, HireDate,
  Address, City, State,
  Country, PostalCode, Phone,
  Fax, Email
FROM employee_2018
UNION ALL
SELECT
  EmployeeId, LastName,
  FirstName, Title, ReportsTo,
  BirthDate, HireDate,
  Address, City, State,
  Country, PostalCode, Phone,
  Fax, Email
FROM employee_2018;
```

2.12.3. Positional Union All (||)

Aligns by position. Requires identical column count. Useful for intentional realignment.[32]:

delightql

```
users_2024(|> (last_name,first_name,age))
  ||
users_2023(|> (LastName,First,Age))
```

32 The below example uses interior relations to shape each relation prior to the `UNION ALL`.

2.12.4. Set Semantics vs Multiset Semantics

All of delightql set operators are actually multiset operators inasmuch as they preserve duplicates. In other words, all set operators are `ALL`-flavored.

If set semantics are required, use `DISTINCT ALL` via `|> %(*)`.

delightql

```
employee_2019(*) |;| employee_2018(*) |> %(*)
```

```SQL
SELECT
  EmployeeId, LastName,
  FirstName, Title, ReportsTo,
  BirthDate, HireDate,
  Address, City, State,
  Country, PostalCode, Phone,
  Fax, Email
FROM employee_2019
  UNION  --- NOT UNION ALL
SELECT
  EmployeeId, LastName,
  FirstName, Title, ReportsTo,
  BirthDate, HireDate,
  Address, City, State,
  Country, PostalCode, Phone,
  Fax, Email
FROM employee_2018;
```

which is equivalent to

```SQL
SELECT DISTINCT * FROM
  (SELECT
    EmployeeId, LastName,
    FirstName, Title, ReportsTo,
    BirthDate, HireDate,
    Address, City, State,
    Country, PostalCode, Phone,
    Fax, Email
  FROM employee_2019
    UNION ALL
  SELECT
    EmployeeId, LastName,
    FirstName, Title, ReportsTo,
    BirthDate, HireDate,
    Address, City, State,
    Country, PostalCode, Phone,
    Fax, Email
  FROM employee_2018)
;
```

2.12.5. Intersects via correlation

Having introduced the operators above, one would assume that a new sigil for intersects is in the offing. Instead delightql chooses to reuse the same syntax for correlations to represent a statement of which columns to intersect on.

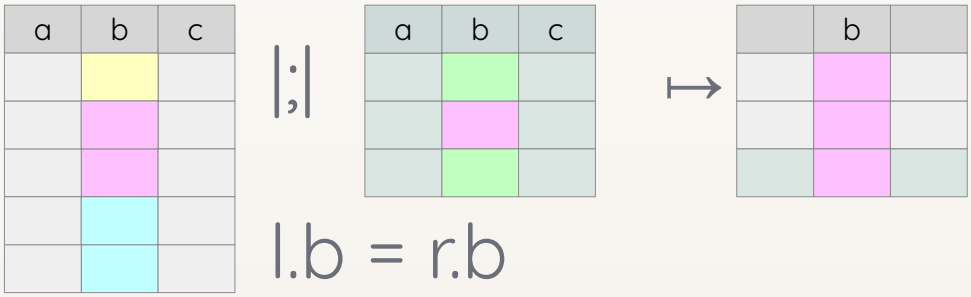


Figure 3: Intersect **ON** via correlation conditions

After any union-flavored multiset operator, conjoin a condition that correlates the previous relations together. From such a union an intersection results:

```delightql
employee_2019(*) as e1 |;|
  employee_2018(*) as e2,
  e1.EmployeeId = e2.EmployeeId
```

SQL's `INTERSECT` only matches on the entire tuple, it lacks an `INTERSECT ON/BY` parameterization. Delightql's correlation syntax lets you choose which columns to match on – a per-column intersection that SQL cannot express without rewriting the query as a pair of `EXISTS` subqueries.

2.12.5.1. Correlation syntax matches alignment mode

The correlation condition should use the same addressing schema as the alignment:

- Name-based modes (`;`, `|;|`) use name-based correlation: `x.col = y.col` or `x.* = y.*`
- Positional mode (`||`) uses positional correlation: `x|1| = y|1|` or `x|*| = y|*|`

The full-tuple shorthand `x.* = y.*` means "match on all column names that appear in both x and y." Columns present on only one side are ignored for matching. Under `|;|` this distinction is moot since the schemas are identical. Under `;` the schemas may be different, and matching on the intersection of names is the only natural reading.

The positional shorthand `x|*| = y|*|` means "match on all column positions."

DQL	Equivalent SQL concept
`x(*) ; y(*) ,x.* = y.*`	INTERSECT ALL CORRESPONDING

DQL	Equivalent SQL concept
`x(*) |;| y(*) ,x.* = y.*`	INTERSECT ALL (Name safe)
`x(*) || y(*) ,x|*| = y|*|`	INTERSECT ALL (positional, = SQL's `INTERSECT ALL`)
`x(*) || y(*) ,x|*| = y|*|`	INTERSECT ALL (positional, = SQL's `INTERSECT ALL`)
delightql `x(*) |;| y(*) ,x.id = y.id`	Per-column intersection (no SQL equivalent)

Table 21: Intersection as union with correlation

To belabor a point, intersection re-purposes correlation syntax that is seen most often with joins to be useful for intersection. To see the difference between a join and an intersection look at how the two tables prior are combined:

Correlation as JOIN ON	Correlation as INTERSECT ON

`employee_2019(*) as e1,`
`  employee_2018(*) as e2,`
`  e1.id=e2.id`
	`employee_2019(*) as e1 |;|`
	`  employee_2018(*) as e2,`
	`  e1.id=e2.id`

`,` between the two tables produces a **join** (rows are paired).	`|;|` between the two tables produces an **intersection** (rows are filtered).

Table 22: Correlation as join versus correlation as intersect

> **Equality and NULL-safety.** The `=` in both columns above looks identical, but the compilation differs. In join position (left column), `=` compiles to SQL `=` – NULLs do not match, because NULL-to-NULL matching in a join can explode row counts . In set correlation position (right column), `=` compiles to `IS NOT DISTINCT FROM` – NULLs match. This is safe because set correlation filters via `EXISTS`, which tests for the presence of a matching row without multiplying output.

> **How intersection is executed in SQL.**

Example:

```
users_2023(*) as u23 ; users_2024(*) as u24,
  u23.email = u24.email
```

SQL

```
SELECT
  id, first_name, last_name, email, age,
  status, country, balance, NULL, NULL, NULL
FROM users_2023 AS u23
  WHERE EXISTS (SELECT 1
    FROM (
      SELECT
        id, first_name, last_name, email, NULL,
        status, NULL, NULL, department,
        salary, created_at
      FROM users_2024 AS u24
    ) AS t1
    WHERE outer_0.email IS NOT DISTINCT FROM
t1.email)

UNION ALL

SELECT
  id, first_name, last_name, email, NULL,
  status, NULL, NULL, department, salary,
  created_at
FROM users_2024 AS u24
  WHERE EXISTS (SELECT 1
    FROM (
      SELECT
        id, first_name, last_name, email, age,
        status, country, balance, NULL, NULL, NULL
      FROM users_2023 AS u23
    ) AS t0
    WHERE t0.email IS NOT DISTINCT FROM
outer_1.email)
```

2.12.6. Minus (Except)

Minus returns rows from the first relation that have no match in the second. A single operator `-` aligns by name:

delightql

```
employee_current(*) - employee_terminated(*)
```

Rows in `employee_current` with no corresponding row (by name) in `employee_terminated`. Schemas must align – if column names differ, rename first:

```delightql
employee_current(*) - employee_terminated(|> *(emp_id as id))
```

2.13. INTERIOR RELATIONS AND LATERAL JOINS

Interior relations unify `EXISTS`, `NOT EXISTS`, scalar subqueries, and lateral joins under one syntax.

An interior relation is a query continuation inside a functor's parentheses:

```
users(|> (last_name,first_name))
```

> **Query Continuation**
>
> A query continuation extends a complete query rightward.
>
> `users(*)^ , age<50^ |> (department)^`
>
> After `users(*)`, the continuation `, age>50 |> (department)` is valid because `users(*)` alone is already meaningful. Likewise, `|> (department)` is valid because `users(*), age>50` is already meaningful.

Interior relations appear wherever tables are allowed. When uncorrelated, they're equivalent to exterior execution:

```
users(*) |> (last_name,first_name)
// equivalent to: users(|> (last_name,first_name))
```

Consider positional union all `||` where interiority crafts the proper alignment and projection:

```delightql
users_2024(|> (last_name,first_name,age))
  ||
users_2023(|> (LastName,First,Age))
```

Interior relations are used in the following:

- scalar subqueries (regardless of correlation)
- `EXISTS` and `NOT EXISTS`
- simple shadowing subqueries
- correlated (non-scalar) subqueries – i.e. lateral joins

2.13.1. Scalar subqueries

Scalar subqueries use interior notation:

```delightql
employee(*) as e
    |> (FirstName,
        LastName,
        Salary,
        employee:( ~> avg:(Salary)) as AvgSalary,
        employee:( , DepartmentName=e.DepartmentName
                   ~> avg:(Salary)) as AvgSalaryInDept)
```

In the above example, two query continuations started with `~>` and `,` execute an uncorrelated and correlated **scalar** subquery respectively.

2.13.2. `EXISTS` and `NOT EXISTS`

The `+` and `\+` prefixes with interior notation create `(NOT) EXISTS`:

```
users(*), orders(*),
  users.id = orders.user_id,
  \+order_items(, orders.id = order_items.order_id)
```

2.13.3. Simple Shadowing

Uncorrelated interior relations are simple shadowing – useful for reshaping before set operations:

```
users(|> (last_name,first_name))
```

but especially for set operators:

```delightql
users_2024(|> (last_name,first_name,age))
  ||
users_2023(|> (LastName,First,Age))
```

```delightql
users_2024(|> *(last_name as LastName,first_name as
First,age as Age))
  |;|
users_2023(*)
```

```delightql
users_2024(; users_2023(*)) as combined,
  org(*), combined.departments=org.dept
  |> (last_name,org.dept)
```

2.13.4. Correlated Table (Lateral Join)

Any table with interiority and correlation to other tables **in the same query** is a lateral join.

Lateral joins may be broken down into three sub-types:

- simple
- aggregate
- top-N

Simple Lateral. A join without aggregation or limits. Replaces multiple scalar subqueries; rarely advantageous over a regular join.

delightql
```
orders(*) ,
  users(, users.id=user_id
        |> (last_name,first_name,email)) as u
  |> (orders.*,last_name,first_name,email)
```

SQL
```
SELECT orders.*, last_name , first_name , email
  FROM (
  SELECT *
    FROM orders
  INNER JOIN (
    SELECT last_name , first_name , email ,
      id  -- promote out of subquery for joining
    FROM users
  ) AS users ON users.id IS NOT DISTINCT FROM user_id
);
```

Aggregate Lateral. Replaces multiple aggregate scalar subqueries. Advantageous when the aggregate key matches the join key.

```
users(*) as u,
  orders(, orders.user_id = u.id |>
            %(user_id
              ~> sum:(total) as total_spent,
                 sum:(tax_amount) as total_tax_amount))
```

SQL
```
SELECT
  *
FROM users AS u
  INNER JOIN (
    SELECT user_id , sum(total) AS total_spent,
sum(tax_amount) AS total_tax_amount
    FROM orders
    GROUP BY user_id
  ) AS orders
ON orders.user_id IS NOT DISTINCT FROM u.id;
```

Top-N Lateral. Returns the top N correlated rows per outer row, avoiding explicit window functions.

```
users(*) as u,
  orders(, orders.user_id = u.id |> #(total desc), #<3)
```

SQL

```
SELECT *
FROM users AS u
JOIN (SELECT
  id, order_id, user_id, customer_id, total,
  tax_amount, shipping_cost, status, created_at,
  shipped_at, delivered_at
FROM (SELECT
  id, order_id, user_id, customer_id, total,
  tax_amount, shipping_cost, status, created_at,
  shipped_at, delivered_at,
  ROW_NUMBER() OVER (
    PARTITION BY
      user_id
    ORDER BY total DESC
  ) AS __dql_rn
FROM orders) AS orders_with_rn
WHERE
  orders_with_rn.__dql_rn <= 3) AS orders
  ON orders.user_id IS NOT DISTINCT FROM u.id;
```

Note how the windowing function above partitions by the correlation join condition.

2.13.5. Summary

The below diagram describes the hierarchy of all places where delightql uses interiority.

Only the tree labeled `interior relations` consists of expressions that are used as actual relations/tables.

```
Interiority:
├── interior relations:
│   ├── correlated (lateral):
│   │   ├── top-N
│   │   ├── simple/multi
│   │   └── aggregate
│   └── uncorrelated
├── (not) exists
└── scalar subqueries
    ├── correlated
    └── uncorrelated
```

2.14. HIGHER-ORDER PIPES

The **R-PIPE** `|>` passes a relation into a unary operator:

delightql
```
employee(*), Salary > 5000
  |> ( LastName )
```

The fundamental unary operators – projection, distinct, group by – have dedicated syntax covered in earlier sections:

delightql
```
foo(*)  |>   ( LastName )
foo(*)  |>  -( FirstName, LastName )
foo(*)  |>  +( length:(LastName) as length_last_name )
foo(*)  |>  %( FirstName, LastName )
foo(*)  |>  %( FirstName, LastName ~> count:(*) )
```

Higher-order predicates extend this pattern. A programmer-defined higher-order predicate can appear as the pipe target:

delightql
```
employee(*)
  |> summarize(*)
```

Given this definition in assertion mode:

delightql
```
summarize(T(*))(*) :-
  T(*)
    ~> ( count:(%LastName)  as
distinct_last_name_count,
         count:(%Department) as
distinct_department_count,
         count:(*)           as total_count,
         avg:(Salary)        as average_salary )
```

the expression `employee(*) |> summarize(*)` expands to:

delightql
```
employee(*)
  ~> ( count:(%LastName)  as distinct_last_name_count,
       count:(%Department) as
distinct_department_count,
       count:(*)           as total_count,
       avg:(Salary)        as average_salary )
```

2.14.1. Piped vs. Direct Invocation

Higher-order predicates can be invoked directly, passing full functor expressions:

```delightql
clean_employees(batch.employee_2019(*))(*)
```

This is equivalent to:

```delightql
batch.employee_2019(*)
  |> clean_employees(*)
```

Direct invocation accepts any relation expression, including filters and projections:

```delightql
clean_employees(batch.employee_2019(*, Salary > 50000))
(*)
```

The piped form's advantage is composability with other pipe operators:

```delightql
batch.employee_2019(*), Salary > 50000,
  Department = "Engineering"
  |> clean_employees(*)
```

2.14.2. Multi-Parameter Piped Invocation

When the piped relation is not the first parameter, use `@` (the f-param placeholder) to mark where it goes — borrowing function-pipe syntax:

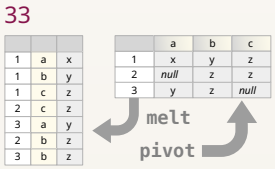
```delightql
-- Definition: scalar first, table second
tagged(label, T(*))(*) :- T(*), ...

-- Piped with @:
users(*) |> tagged("young", @)(*)
```

Without `@`, the piped relation fills the first parameter by default. When the first parameter is a scalar, this fails. The `@` placeholder makes the target position explicit.

2.15. PIVOT AND MELT

Melting and pivoting are inverse transformations between two table shapes containing the same data. The "long

skinny" table stores attributes as data – normalized, often resembling key-value pairs. The "short wide" table lifts attributes to metadata – they become column names. [33]

[33]


Both transformations are possible in pure SQL given:

1. Support for compound data (JSON objects, arrays)
2. Ability to join against compound data (`unnest`, `json_each`)
3. For pivoting: attribute values must be known at query-write time to become column names

2.15.1. Melt

Melting normalizes denormalized data. A common case: data transfers between organizations where a single row contains multiple relations.

Consider `claim_header` with four diagnosis columns that should be normalized into separate rows:

delightql
```
claim_header(*), _( Diagnosis, Description,
DiagnosisNumber

-------------------------------------
                    diag_1, diag_description1, 1;
                    diag_2, diag_description2, 2;
                    diag_3, diag_description3, 3;
                    diag_4, diag_description4, 4 )
  |> (claim_id, DiagnosisNumber, Diagnosis, Description)
```

The anonymous table (lines 1–5) maps each source column set to a row. Joining it to `claim_header` with no condition produces one output row per diagnosis per claim – four times the original cardinality. The projection (line 6) retains only the normalized columns.

The transpiled SQL uses JSON as an intermediate representation: [34]

[34] The use of JSON functions is an implementation detail – arrays with `unnest` would work equally. The result contains no JSON; it is a normal table.

```sql
WITH
  _premelt_claim_header AS (
    SELECT
      claim_id,
      json_array(
        json_array(
          diagnosis_1,
          diagnosis_1_description,
          1
        ),
        json_array(
          diagnosis_2,
          diagnosis_2_description,
          2
        ),
        json_array(
          diagnosis_3,
          diagnosis_3_description,
          3
        ),
        json_array(
          diagnosis_4,
          diagnosis_4_description,
          4
        )
      ) AS _melt_packet
    FROM claim_header
  )
SELECT
  claim_id,
  json_extract(j.value, "$[2]") AS DiagnosisNumber,
  json_extract(j.value, "$[0]") AS Diagnosis,
  json_extract(j.value, "$[1]") AS Description
FROM _premelt_claim_header
JOIN json_each(_melt_packet) AS j;
```

2.15.2. Pivot

Pivoting is a `GROUP BY` that rotates row-oriented data into columns. The group key defines the entity; an attribute column becomes column names; a value column fills them.

Given `student_scores`:

last-name	firstname	subject	evaluation_result	evaluation_day
Smith	John	Music	7.0	2016-03-01
Smith	John	Maths	4.0	2016-03-01
Smith	John	History	9.0	2016-03-22

last-name	firstname	subject	evaluation_result	evaluation_day
Smith	John	Lan-guage	7.0	2016-03-15
Smith	John	Geogra-phy	9.0	2016-03-04
Gabriel	Peter	Music	2.0	2016-03-01
Gabriel	Peter	Maths	10.0	2016-03-01
Gabriel	Peter	History	7.0	2016-03-22
Gabriel	Peter	Lan-guage	4.0	2016-03-15
Gabriel	Peter	Geogra-phy	10.0	2016-03-04

Table 23: Sample student_scores data

A pivot on `subject` produces:

last-name	firstname	geogra-phy	history	maths	mu-sic	lan-guage
Gabriel	Peter	10.0	7.0	10.0	2.0	4.0
Smith	John	9.0	9.0	4.0	7.0	7.0

Table 24: Pivoted result – subjects become columns

delightql

```
1 student_scores(*),
2   subject in ("Music"; "Maths"; "History"; "Language"; "Geography")
3   |> %( firstname, lastname
4          ~>
5        evaluation_result of subject )
```

- Line 3: `firstname, lastname` defines the entity (group key), determining output cardinality
- Line 2: the `in` clause constrains which attribute values become columns
- Line 5: `evaluation_result of subject` rotates values into attribute-named columns

The `in` clause is required. Pivoting has compile-time semantics – the output schema is determined by the query, not the data. Without a fixed set of attribute values, the column names would be unknowable.

The transpiled SQL:

SQL

```sql
WITH _prepivot_student_scores AS (
  SELECT
    lastname,
    firstname,
    json_group_object(
      subject,
      json_object('evaluation_result', evaluation_result)
    ) AS _pivot_packet
  FROM student_scores
  GROUP BY lastname, firstname
)
SELECT
  lastname,
  firstname,
  json_extract(_pivot_packet, '$.Geography.evaluation_result') AS
geography,
  json_extract(_pivot_packet, '$.History.evaluation_result') AS
history,
  json_extract(_pivot_packet, '$.Maths.evaluation_result') AS maths,
  json_extract(_pivot_packet, '$.Music.evaluation_result') AS music,
  json_extract(_pivot_packet, '$.Language.evaluation_result') AS
language
FROM _prepivot_student_scores;
```

2.15.2.1. Multiple Value Columns

The source table included `evaluation_day`, unused above. Multiple `of` clauses pivot additional columns:

last-name	first-name	geogra-phy	geography_day	his-tory	history_day	…
Gabriel	Peter	10.0	2016-03-04	7.0	2016-03-22	
Smith	John	9.0	2016-03-04	9.0	2016-03-22	

Table 25: Pivot with multiple value columns

delightql

```
1 student_scores(*),
2   subject in ("Music"; "Maths"; "History"; "Language"; "Geography")
3   |> %( firstname, lastname
4           ~>
5         evaluation_result of subject,
6         evaluation_day of :"{subject}_day" )
```

Lines 5–6 introduce two pivot column sets. The second uses a format function to distinguish column names (`Music_day`, `Maths_day`, etc.). When pivoting multiple value columns, the attribute expression after `of` must differ – here, `subject` versus `:"{subject}_day"`.

2.15.3. Pivot Syntax

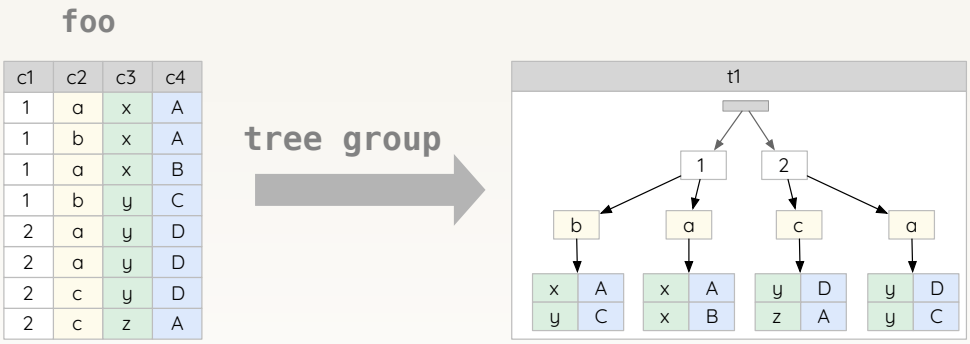
The `of` keyword rotates values into attribute-named columns. The grammar:

```
<value_column> of <attribute_column>
<value_column> of :<format_string>
```

The attribute column must be constrained by an `in` clause. When pivoting multiple value columns, each `of` expression must produce distinct column names – hence the format string option.

2.16. TREE GROUPS

Tree grouping transforms flat relations into nested JSON structures. Each nesting level corresponds to a `GROUP BY` – the tree's shape reflects the grouping hierarchy.



Delightql provides this capability through compound data constructors (`{ }`, `[ ]`) used in reduction positions. The resulting JSON is not general-purpose – it maps relations to a tree normal form where each level represents a distinct grouping context.

Two forms exist:

- **Data-oriented**: produces arrays of objects; grouping columns become object fields
- **Metadata-oriented**: produces objects with data values as keys; a single column's values become the key names

Full JSON functionality remains available through the target SQL's native functions (`json_object`, `json_array`, etc.).

2.16.1. Compound Data Constructors (Recap)

Constructor	Scalar Position	Aggregate Position
`{ }`	Record (string-indexed)	Table of records
`[ ]`	Tuple (numeric-indexed)	Table of tuples

Table 26: Compound data constructors by position (recap)

2.16.2. Tree Group Syntax

Nested tree groups are created by nesting compound constructors with `~>` introducing each level:

```delightql
employee(*)
  ~> { Title,
       "people": ~> {FirstName, LastName},
       State } as people_by_title_and_state
```

Reading the syntax. The `~>` marks tree group boundaries. Columns between a `~>` and either the next `~>` or a closing enclyph (`}`, `]`, `)`) belong to that level's group:

```delightql
// level 1                level 2              L2 end    L1 end
// start                  start
// ↳                      ↳                        ↱         ↱
   ~> { Title, "people": ~> {FirstName, LastName},  State }
```

- `Title` and `State` belong to level 1 (the top-level tree group)
- `FirstName` and `LastName` belong to level 2 (nested within level 1)

The grouping is hierarchical: level 2 groups are computed within each distinct combination of level 1 columns.

2.16.2.1. Terminology

- **tree group**: The set of columns whose distinct combinations form one level of the tree
- **tree group variables**: The columns belonging to a tree group
- **nested tree group**: A tree group inside another tree group
- **tree group induction**: Using a compound constructor in reduction position to create an interior table

2.16.3. Data-Oriented Tree Grouping

Data-oriented tree grouping uses `~>` followed by a compound constructor. The result is an array of objects (or tuples), one per distinct combination of tree group variables.

Simple example:

```delightql
employee(*)
  ~> { Title, State } as title_and_state
```

Returns one row containing an array of all distinct `{Title, State}` combinations.

Nested example:

```delightql
employee(*)
  ~> { Title,
       "people": ~> {FirstName, LastName},
       State } as people_by_title_and_state
```

Returns a single-row, single-column table:

people_by_title_and_state


```
[
 { "Title": "Account Representative",
   "State": "PA",
   "people": [
     { "FirstName": "Stafani", "LastName": "Hurton" },
     { "FirstName": "Jenda", "LastName": "Bownd" }
   ]
 },
 { "Title": "Programmer",
   "State": "PA",
   "people": [
     { "FirstName": "Clareta", "LastName": "Cuss" }
   ]
 },
 { "Title": "Programmer",
   "State": "GA",
   "people": [
     { "FirstName": "Anita", "LastName": "Aburrow" }
   ]
 },
 { "Title": "VP",
   "State": "OH",
   "people": [
     { "FirstName": "Drusi", "LastName": "Sachno" }
   ]
 },
 { "Title": "VP",
   "State": "PA",
   "people": [
     { "FirstName": "Frazer", "LastName": "Vido" },
 { "FirstName": "Corney", "LastName": "Treherne" }
```

people_by_title_and_state
]   }]

Table 27: {#tbl:array-tree-group}

Transpilation. Tree grouping uses JSON aggregation functions as intermediates:

SQL

```
SELECT
  json_group_array(
    json_object(
      'Title', Title,
      'State', State,
      'people', people
    )
  ) AS people_by_title_and_state
FROM (
  SELECT
    Title,
    State,
    json_group_array(
      json_object('FirstName', FirstName, 'LastName',
LastName)
    ) AS people
  FROM employee
  GROUP BY Title, State
);
```

The nested `GROUP BY` mirrors the nested ~>. Each tree group level becomes a subquery with its own grouping and JSON aggregation. The JSON functions are implementation details – the result is a standard column containing structured data.

Three-level example:

delightql

```
employee(*)
  ~> { Title,
       "people_by_state":
         ~> { State,
              "people": ~> {FirstName, LastName} } }
    as people_by_state_within_title
```

Groups first by `Title`, then within each title by `State`, then collects people within each state.

Sibling tree groups:

Multiple nested groups at the same level share their parent's context but are otherwise independent:

```delightql
employee(*)
  ~> { Title,
       "people_by_state": ~> { State, "people": ~>
{FirstName, LastName} },
       "cities": ~> [City] }
    as nested_with_siblings
```

The `people_by_state` and `cities` tree groups are siblings – both nested within `Title`, neither containing the other.

Sibling tree groups share their parent's context but aggregate independently. The relationship between siblings —which person was in which city – is not preserved. This is inherent to the structure: siblings represent independent projections of the grouped data. [35]

35 Trees with siblings satisfy TNF-G but not TNF-R; they cannot round-trip losslessly. (See Appendix A.)

2.16.4. Metadata-Oriented Tree Grouping

Metadata-oriented tree grouping elevates data values to JSON keys. A column's distinct values become the keys of a single object rather than elements of an array.

The syntax uses `:~>` after a bare identifier:

```delightql
employee(*)
  ~> Title: ~> {FirstName, LastName} as people_by_title
```

The result is an interior record (one object), not an interior table (array of objects):

```
{
  "General Manager": [
    { "FirstName": "Andrew", "LastName": "Adams" }
  ],
  "IT Manager": [
    { "FirstName": "Michael", "LastName": "Mitchell" }
  ],
  "Sales Manager": [
    { "FirstName": "Nancy", "LastName": "Edwards" }
  ]
}
```

Distinguishing syntax:

- Normal keys are quoted strings: `"people":`
- Metadata keys are bare identifiers followed by `:~>`: `Title: ~>`

Restriction: Only one column can serve as a metadata key per level – the object can have only one set of keys. This constraint reflects JSON's structure: two metadata-keyed objects with the same key type would create ambiguous destructuring. Metadata-oriented trees satisfy TNF-M. (See Appendix A.)

Within a regular group by:

```delightql
employee(*)
  |> %( State
          ~>
        Title: ~> {FirstName, LastName} as
people_by_title )
```

Returns one row per state, each containing an object keyed by title.

2.16.5. Tree Distinction

Tree structures can serve as grouping columns, enabling aggregation alongside hierarchical output:

```delightql
employee(*)
  |> %( { Title,
          "people": ~> {FirstName, LastName},
          State } as people_by_title_and_state
          ~>
        sum:(Salary), count:(*) )
```

Restriction: Columns referenced in nested tree groups cannot also appear as explicit grouping columns:

```delightql
// INVALID: LastName appears in tree group and as
grouping column
employee(*)
  |> %( { Title, "people": ~> {FirstName, LastName},
State } as tree,
        LastName
          ~>
        sum:(Salary) )
```

Columns not referenced in the tree may be added:

```delightql
employee(*)
  |> %( { Title, "people": ~> {FirstName, LastName},
State } as tree,
        DepartmentId
          ~>
        sum:(Salary), count:(*) )
```

2.16.6. Tree Destructuring

Tree destructuring is the inverse of tree grouping – it flattens nested JSON back into rows.

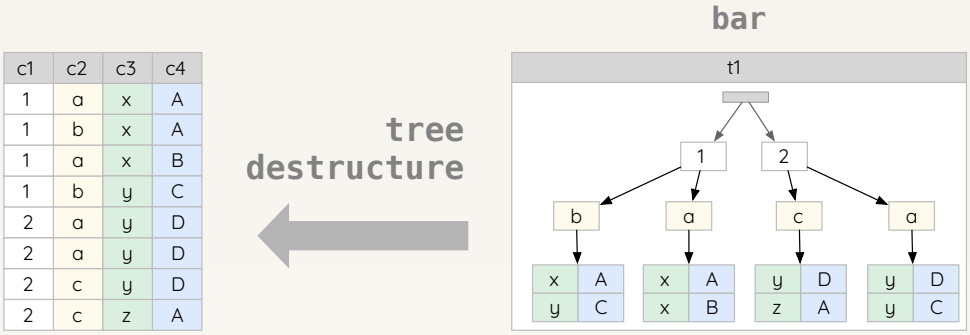


Figure 4: group and destructure

The TREE-UNIFY sigil `~=` matches a JSON column against a destructuring pattern:

```delightql
table_with_json(*)
  , people_by_state_within_title ~= ~> { Title,
             "people_by_state":
               ~> { State,
                    "people": ~> {FirstName,
LastName} } }
  |> -(people_by_state_within_title)
```

The pattern syntax mirrors construction syntax. Each `~>` level multiplies rows – the result is the Cartesian product of all nested arrays.

Array vs object matching:

```delightql
// Matches an ARRAY of objects  --  multiplies rows by
array length
p ~= ~> { Title, State }

// Matches a single OBJECT  --  extracts fields, no
multiplication
p ~= { Title, State }
```

The ~> in destructuring means "iterate over this array," just as in construction it means "aggregate into this array."

Renaming during destructuring:

The string key matches the JSON; the identifier after : names the output column:

```delightql
, people_by_state_within_title ~= ~> { Title,
       "people_by_state": ~> { State, "people":
peeps } }
```

Here `"people"` matches the JSON key; `peeps` becomes the column name. The `peeps` column contains the nested array as-is, not destructured.

Staged destructuring:

Destructure incrementally by chaining ~= operations:

```delightql
table_with_json(*)
  , nested ~= ~> {country, "users": sub_users}
  , sub_users ~= ~> {FirstName, LastName}
  |> -(nested)
```

The first ~= extracts `country` and keeps `sub_users` as a JSON array. The second destructures `sub_users` into individual rows. Stop at any level to preserve nested structure.

Metadata-oriented destructuring:

The :~> syntax works symmetrically – object keys become column values:

```delightql
temp(*), json_col ~= ~> country: ~> {FirstName,
LastName}
  |> -(json_col)
```

Given an object keyed by country names, this extracts the key into a `country` column and iterates the nested arrays.

Binding semantics:

Column names in the pattern match JSON keys by name. If the pattern says `FirstName` and the JSON has `"FirstName"`, they bind. A mismatched name produces nulls – there is no compile-time validation against JSON structure.

2.16.7. Pathing in Tree Patterns

Destructuring patterns support direct pathing, eliminating the need to match intermediate structure. The pathing syntax (`.path.to.field`) reaches into nested JSON without declaring every level.

Basic pathing:

```delightql
_(json @ {"name": "app", "config": {"server": {"port": 3000}}})
  |> (json:{.config.server.port})
```

The path `.config.server.port` extracts the value directly.

Pathing in destructuring:

Instead of matching the full structure:

```delightql
j ~= { name, "config": { "server": { port, host },
"database": { url } } }
```

Path directly to what you need:

```delightql
j ~= {
  name,
  .config.server.port,
  .config.server.host,
  .config.database.url
}
```

Pathing with rename:

Combine pathing with `as` to name the output column:

```delightql
user_data ~= ~> {
  country,
  .name_info.last_name as ln,
  .name_info.first_name as fn
}
```

Mixed matching and pathing:

Structural matching and pathing can combine in a single pattern:

```delightql
j ~= {
  name,
  version,
  .dependencies.react,
  .dependencies.next
}
```

Here `name` and `version` match top-level keys directly; the `.dependencies.*` paths reach into nested structure.

Pathing in projection:

Pathing works outside destructuring patterns, in normal projection:

```delightql
_(json @ {"name": "app", "scripts": {"dev": "next dev",
"build": "next build"}})
  |> ({
    "name": json:{.name},
    "scripts": json:{.scripts}
  })
```

2.16.8. Interior Drill-Down

Tree destructuring with `~=` requires the user to spell out the interior schema – every level of nesting must be declared in the pattern. When the schema is statically known (tree groups from a view, CTE, or inline query), `.column(*)` provides a shorter, self-documenting alternative.

Syntax. `.column_name(*)` as a suffix on any relation expression. The `(*)` means "all columns of the interior relation." Specific columns are also supported: `.entities(name, type)`. The operator is chainable: `.entities(*).columns(*)`.

Context carry-forward. Outer columns remain available after a drill-down. `.entities(*)` produces entity-level columns plus all columns from the enclosing level, minus the exploded column itself. This is lateral-join semantics – each interior row inherits the context of its parent row.

Example – CTE drill-down:

```delightql
users(*) |> %(country ~> {first_name, last_name} as
people) : by_country
by_country(*).people(*)
```

This produces one row per person, with `country` carried forward from the grouping level.

Example – chained drill-down:

```delightql
main::(*).entities(*).columns(*)
  , entity_name = "users"
```

Each `.name(*)` step explodes one level of nesting. Columns from all prior levels remain available for filtering.

Equivalence with `~=`. The same query written both ways:

delightql
```
// Drill-down form:
main::(*) |> (entities) .entities(*)

// Equivalent ~= form:
main::(*)
  , entities ~= ~> {name, type, doc, "columns": ~>
{col_name, col_type, col_pos}}
  |> -(entities)
```

The drill-down form does not require the user to know the interior schema.

2.16.9. Narrowing Destructure

The `~=` operator and interior drill-down both carry context forward – outer columns survive into the result. This is the correct default for relational composition, but it requires projecting out the intermediate columns when they are no longer needed:

delightql
```
j(*), j ~= {.packages} |> -(j)
  , packages ~= ~> {.version, .name, .description} |> -
(packages)
```

When the intent is to drill into a column, extract fields, and discard everything else, the `.column{...}` operator expresses this more efficiently:

delightql
```
j(*)
  |> .j{.packages}
  |> .packages{.version, .name, .description}
```

Each step replaces the current row with the destructured result.

When to use which.

Form	Carries context	Use case
`~= pattern`	Yes	General relational destructuring; join with outer columns
`.col(*)`	Yes	Drill-down when schema is known; outer columns needed

Form	Carries context	Use case
`.col{...}`	No	Navigate into nested JSON; only interior fields matter

Example – cargo metadata:

```delightql
j(*)
  |> (j:{.packages} as packages)
  |> .packages{.version, .name, .description}
```

The path extraction `j:{.packages}` pulls the packages array out of the top-level object; then `.packages{...}` iterates and extracts fields. The result is a flat table with `version`, `name`, and `description` columns – no intermediate columns to clean up.

2.16.10. Null Elision in Tree Groups

When an outer join feeds into a tree group, the join pads unmatched rows with NULLs. In a flat relation this is the only way to represent "no match" – NULL serves as a sentinel for absence. Trees have no such limitation: an empty array `[]` directly represents "no children."

Tree groups decode this flat-world encoding. When **all** value columns in a contributing row are NULL, the row is elided from the array. The result is `[]`, not `[{"col": null, ...}]`.

Example:

```delightql
parents(*) : _(id, name ---- 1, "Alice"; 2, "Bob"; 3,
"Charlie")
children(*) : _(parent_id, toy ---- 1, "doll"; 1,
"ball"; 2, "car")

parents(*), children?(*), parents.id =
children.parent_id
  |> %(name ~> {toy} as toys)
```

Charlie has no children. The outer join produces `(3, "Charlie", NULL)`. Without null elision, the tree group would produce:

name	toys
Alice	[{"toy":"doll"},{"toy":"ball"}]

name	toys
Bob	[{“toy”:“car”}]
Charlie	[{“toy”:null}]

With null elision:

name	toys
Alice	[{“toy”:“doll”},{“toy”:“ball”}]
Bob	[{“toy”:“car”}]
Charlie	[]

Scope. Null elision applies to both forms:

- `~> {a, b, c}` – curly (object) tree groups
- `~> [a, b, c]` – bracket (tuple) tree groups

The elision rule. A row is elided when every value column in the constructor is NULL. If any value column is non-null, the row is preserved. This means a row like `{"name": "Alice", "age": null}` survives – only fully-null rows (the signature of outer-join padding) are dropped.

Parent entity preservation. Null elision never removes the parent entity. Charlie still appears in the result – only the contents of the nested array change (from `[{"toy":null}]` to `[]`). The **GROUP BY** produces a row for Charlie’s grouping key; the aggregate column becomes an empty array rather than an array containing a null-valued object.

Round-trip behavior. Destructuring an empty array produces zero rows. After null elision, destructuring Charlie’s `[]` eliminates Charlie from the flat result – which is the same behavior as an inner join.

2.17. META-IZE OPERATOR

The meta-ize operator reifies a relation’s schema as a relation – each column becomes a row. Where `*` inside a functor returns all data rows, `^` returns all columns as rows of metadata.

2.17.1. Schema as Relation (^)

```delightql
users(^)
```

This returns one row per column in `users`:

colname	colposition	coltype
id	1	INTEGER
first_name	2	TEXT
last_name	3	TEXT
age	4	INTEGER
email	5	TEXT

Table 31: Output of `users(^)`

The `^` operator belongs to the continuation operator family – unary operators that transform table access:

Operator	Meaning
`*`	Qualify column names (data access)
`()`	Unqualified columns (natural join candidate)
`.(cols)`	USING semantics on specific columns
`^`	Column metadata as rows
`^^`	Full DDL metadata as rows

Table 32: Table continuation operators

These operators compose freely: `users(*.(id))` means "qualified + USING on id."

2.17.2. Postfix Form

`users(^)` is sugar for `users(*) ^`. The postfix form works on any relational expression, not just base tables:

```delightql
-- schema of a projection (2 rows)
users(*) |> (first_name, age) ^

-- schema of a join
users(*), products(*) ^

-- schema of an aggregation
users(*) |> %(country ~> count:(*) as n) ^
```

The postfix `^` applies to the entire expression to its left, returning its schema as a relation.

2.17.3. Composability

Because `^` produces a regular relation, all DQL operations apply – filtering, projection, pipes, joins, and set operators:

delightql
```
-- text columns only
users(^), coltype = "TEXT" |> (colname)
```

delightql
```
-- columns shared between two year-partitioned tables
users_2024(^) |;| users_2023(^), x.* = y.*
```

delightql
```
-- filter schema of an optionally-joined table
department?(^), coltype = "TEXT"
```

> The output of ^ is itself a relation with a fixed schema (colname, colposition, coltype). Applying ^ to a ^ result would return the schema of the metadata relation – three rows describing colname, colposition, and coltype themselves.

3. DATA DEFINITION LANGUAGE (DDL)

DDL is the set of features that create, modify, or delete schema entities. This is the SQL definition.

Delightql's DDL encompasses SQL's DDL and features with no direct SQL mapping (higher-order predicates, ER-context rules). The thematic concern is **reusability**: definitions, tables, and data that can be authored, loaded, and referenced.

This section covers:

- **Relational rules**. Views, higher-order views, ER-context rules, and sigma predicates.
- **Function rules**. Reusable domain functions.
- **Facts**. Axiomatic ground data.
- **Namespaces**. Organization and visibility of all the above.

3.1. BASICS

> **Assertion mode vs query mode**. Delightql, like Prolog, distinguishes two programming modes:
>
> - **Query mode**. Expressions entered into a REPL that execute immediately. This was the subject of the first book in this reference.
> - **Assertion mode**. Files that contain definitions for later use.
>
> The features in this DDL section are assertion-mode constructs.

Assertion mode has two general syntactic forms: rules and facts.

3.1.1. Rules

The general form of a rule is

```
<HEAD>  <NECK>  <BODY>
```

```
young_users(*)
  :- adults(*), age < 20
```

In the above example:

- `young_users(*)` is the `HEAD`
- `:-` is the `NECK`
- `adults(*), age <20` is the `BODY`. The body may use any DQL feature–the entire previous book applies here.

3.1.2. Facts

Facts are functor forms with grounded data.

```delightql
parent("Abraham", "Isaac")
```

This looks like a query. The syntax is context dependent. In assertion mode, i.e. in a file with rules and definitions, this syntax defines extensional data – axiomatic truths with no derivation.

3.1.3. The Two Necks

The **neck** separates a rule's head from its body. Delightql has two necks, each defining a different scope and extent:

Neck	Name
:	Shadow neck
:-	Rule neck

Table 33: The two neck operators

3.1.3.1. Extent vs Scope

There is a difference between when and where a rule definition is available. The terminology is known by the names extent and scope.

Scope refers to the spatial visibility of a definition. It asks where an abstraction – a name – is available for use.

Extent is temporal lifetime. It asks when an abstraction is available for use. In contrast to regular programming languages, extent matters more for databases where tables and views outlive a process.

The necks in delightql map to different types of scope and extent:

- Query-extent (`:`) – Exists only for the duration of one query. These are CTEs. These also have a scope limited by a query.
- Session-extent (`:-`) – Exists for the duration of the connection. These are temporary views, tables or inlinable definitions. Their scope is determined by namespacing – the subject of a later chapter.
- Permanent-extent – Persists after disconnection. These are tables and views.

3.1.3.2. Shadow Neck `:`

The shadow neck defines a momentary definition with limited scope. The definition exists only for the single query in which it appears:

```
young(x) : users(x), age < 30
young(*)
```

A shadow-neck definition may shadow an existing table or view of the same name for the duration of the query. This scoping behavior is unique to the shadow neck.

Shadow-neck definitions are not DDL – they are reviewed here for syntactic similarity to rules.

3.1.4. Rule Neck (`:-`)

```
young_users(*) :- valid_users(*), age < 30
```

The rule neck (`:-`) creates a definition that is equivalent to SQL's `CREATE TEMP VIEW`. Delightql may choose to create temporary views to implement this abstraction, but may also choose to do expression rewriting.

3.2. RULES

The syntax of rules obey the general form:

```
<HEAD>  <NECK>  <BODY>
```

In delightql these rules may be used for any of the following:

- Views
- Tables
- Higher-order views
- ER-contexts
- Sigma predicates
- Functions

All of these use the `:-` neck. The first five define relations; functions define the special subset of relations that are functions.

3.2.1. Arity and Naming

A rule's **arity** is the number of arguments in its head.

Definitions invoked with explicit arguments – functions, sigma predicates, higher-order rules – may share a name with different arities. The call site disambiguates:

delightql

```
add:(x) :- x + 1
add:(x, y) :- x + y

// Invocation is unambiguous
add:(5)      // add/1
add:(5, 3)   // add/2
```

Definitions queried with the glob – views, tables, facts – must have fixed arity. The glob presumes a single schema:

delightql

```
employee(id, name) :- ...
employee(*)  // expects one schema
```

If you can write `foo(*)`, all `foo` definitions must agree on arity. With argumentative heads, agreement is stricter: same arity AND same names at each position. See Head Semantics for the full rules.

3.2.2. Head Semantics

The head of a rule names the entity and declares what it exposes. How the head is written determines the output schema and how multi-clause entities combine.

3.2.2.1. Two Head Forms

3.2.2.1.1. Glob head

```delightql
young(*)
  :- people(*), age > 20
```

The glob `*` passes through whatever the body produces. The entity inherits its schema from the body. This is the permissive form – the head makes no claim about column names or count.

3.2.2.1.2. Argumentative head

```delightql
young(name, age)
  :- people(*), age > 20
```

The head declares the entity's output schema: exactly `name` and `age`, in that order. Every clause must satisfy this contract – the body must produce columns with those names (among possibly others).

The body may be wider than the head. The head projects from the body by name, so wide source tables need not be narrowed in the body before the head can name the subset. If the body does not produce a column named in the head, then it is an error.

3.2.2.2. Ground Terms in the Head

A head position can hold a ground term (a literal) instead of a free variable (a column name).

```delightql
bracket("old", last_name, first_name)
  :- people(*), age > 40
```

Ground terms in the head inject constants into the output and provide choice semantics for multi-clause disjunctive rules.

3.2.2.3. Multi-Clause Rules

```delightql
bracket("old", last_name, first_name)
  :- people(*), age > 40
bracket("toddler", last_name, first_name)
  :- people(*), age < 4
bracket(category, last_name, first_name)
  :- people(*)
```

Multi-headed rules with the exact same named and shaped head are called disjunctive rules. The disjunctive in disjunctive rules is a reference to the logical `OR` and manifests in different ways depending on the context:

- sum types in algebraic data types
- tagged unions and/or variants in many programming languages
- union in set theory (and therefore SQL)
- choice in grammar rules
- `OR` in logic

The meaning of multi-headed clauses is exactly **UNION ALL**.

3.2.2.3.1. Disjunctive Rules: Consistency of Head Forms

All clauses of the same entity must use the same head form – either all glob or all argumentative. Mixing is an error:

```delightql
-- OK: all glob
data(*) :- source_a(*)
data(*) :- source_b(*)

-- OK: all argumentative
data(x, y) :- source_a(*)
data(x, y) :- source_b(*)

-- ERROR: mixed head forms
data(*) :- source_a(*)
data(x, y) :- source_b(*)
```

3.2.2.4. Disjunctive Rules: Union Semantics by head form

Glob heads and argumentative heads use different union strategies:

Strategy	Alignment
Glob head (smart union corresponding)	by name, NULLs for gaps
Argumentative head	positional AND by name

Glob heads use smart union corresponding: columns align by name across clauses, and columns missing from a clause are filled with `NULL`. This permits clauses with different source tables and column sets.

3.2.2.4.1. Column naming with ground terms

Argumentative heads require strict agreement: every clause must have the same number of positions, and **free variables at each position must use the same name across all clauses**. If clause 1 has `(name, age)` and clause 2 has `(age, name)` then this is an error.

Ground terms (constants) are nameless – they do not contribute a column name for a position. Free variables provide names. The rules:

- If a position has free variables in one or more clauses, all those free variables must use the **same name**. Constants in other clauses are compatible (they provide a value but no name).
- Conflicting names at the same position is an error.

```delightql
-- OK: "category" names position 1; constants in other
clauses are compatible
bracket("old", last_name, first_name)
  :- people(*), age > 40
bracket("toddler", last_name, first_name)
  :- people(*), age < 4
bracket(category, last_name, first_name)
  :- people(*)

-- ERROR: position 1 named "motto" in one clause, "city"
in another
bracket("old", last_name, first_name)
  :- people(*), age > 40
bracket(motto, last_name, first_name)
  :- people(*)
bracket(city, last_name, first_name)
  :- people(*)
```

3.2.3. Higher-Order Rules

Higher-order rules accept tables or scalars as parameters. SQL calls these table-valued functions; Prolog would call them higher-order predicates.

3.2.3.1. Syntax

A higher-order rule is very easy to see. It has two sets of parentheses: the first for parameters – input values, the second for output values.

```delightql
department_employee_count(E(*), D(*))(department,
employee_count) :-
  E(*), D(*.(DepartmentId))
    |> %(D.department ~> count:(*) as employee_count)
```

In the above example, the parameters `E(*)` and `D(*)` are inner glob functors – they accept whatever tables are passed at invocation. The `(*)` signals that the body will reference these tables' columns by name.

3.2.3.2. Direct Invocation

As discussed in the section on DQL, tables can be passed in directly:

```delightql
department_employee_count(employee_2019(*),
department_2019(*))(*)
```

The call site mirrors the definition head: each table parameter is a full functor expression. This makes the call self-documenting – you can see which arguments are tables and which are scalars without looking up the definition.

Because call-site arguments are relation expressions, they can compose:

```delightql
department_employee_count(
  employee_2019(*, Salary > 50000),
  department_2019(*)
)(*)
```

Here the first argument is a filtered relation – only high earners are counted.

3.2.3.3. Piped Invocation

Pipes can be used on any higher-order predicate that takes a table-valued parameter:

```delightql
clean_employees(T(*))(*) :-
  T(*) as t
    |> $(trim:())(t.LastName, t.FirstName)
    |> $(to_iso:())(t.BirthDate, t.HireDate)
```

```delightql
employee_2019(*)
  |> clean_employees(*)
```

The piped relation fills the first parameter. The `(*)` after the rule name is the output schema, not an input functor.

Chaining is possible:

```delightql
mask_ssn(T(*), mask_value)(*) :-
  T(*) |> $$(mask_value as ssn)
```

```delightql
employee_2019(*)
  |;| employee_2018(*)
  |;| employee_2017(*)
  |> clean_employees(*)
  |> mask_ssn("***-**-****")(*)
```

Note. As with function pipes, the relation is piped into the first parameter of the higher-order predicate. If the higher-

order predicate has multiple parameters, the other values must be set.

Multi-parameter piped invocation. When the piped relation is not the first parameter, use `@` (the f-param placeholder) to mark where it goes – the same syntax as function pipes:

```delightql
-- Definition: scalar first, table second
tagged(label, T(*))(*) :- T(*), ...

-- Direct invocation (always works):
tagged("young", users(*))(*)

-- Piped invocation with @:
users(*) |> tagged("young", @)(*)
```

The `@` tells the compiler which parameter receives the piped relation. Without `@`, the piped relation fills the first parameter by default – which fails when the first parameter is a scalar.

3.2.3.4. Scalar Parameters

A bare identifier without parentheses is a scalar parameter. It binds a single value used directly in body expressions:

```delightql
high_earners(T(*), salary_floor, min_count)(*) :-
  T(*), Salary > salary_floor,
    department(*.(DepartmentId))
    |> %(department ~> count:(*) as employee_count),
    employee_count > min_count
```

```delightql
high_earners(employee(*), 50000, 10)(*)
```

Scalar parameters accept single values only – not tables, not pipes, not multi-row inline data. Functor expressions are visually distinct from scalar literals, so comma separation is unambiguous.

3.2.4. Inner Functors

Higher-order parameters come in four flavors, distinguished by **syntax** in the definition head:

Form	Kind	Name
`T(*)`	table, structurally typed	inner glob functor
`T(a, b)`	table, positionally typed	inner argumentative functor
`n`	scalar value	scalar parameter
`f:()`	function value	function parameter

The syntax alone tells the language what each parameter accepts. Capitalization is conventional – programmers should uppercase table parameters and lowercase scalars for readability, but the language does not require it.

3.2.4.1. Inner Glob Functors

An **inner glob functor** `T(*)` is **structurally typed**: the body references columns by name, and any table that has those columns is accepted regardless of width.

```delightql
clean_employees(T(*))(*) :-
  T(*) as t
    |> $(trim:())(t.LastName, t.FirstName)
    |> $(to_iso:())(t.BirthDate, t.HireDate)
```

The parameter `T(*)` accepts any table with `LastName`, `FirstName`, `BirthDate`, and `HireDate` columns – it may have other columns too. This is duck typing: if it has the right columns, it fits.

3.2.4.2. Inner Argumentative Functors

An **inner argumentative functor** `T(a, b)` is **positionally typed**: the input must have exactly two columns, and they are renamed to `a` and `b` inside the body. The caller's original column names are overwritten.

```delightql
foo(T(label, value))(*) :-
  T(*), value > 10 |> (label)
```

The names `label` and `value` are column aliases available in the body. The definition simultaneously declares the arity (two columns) and provides names for positional access.

The advantage of the argumentative functor is in the calling convention, called scalar lifting. Because the definition

declares a positional contract, a call site may pass bare scalars instead of a table:

```delightql
foo("first", 2)(*)
```

The scalars are positionally matched to the declared columns `label` and `value` and lifted into a one-row table. This cascades to stacked notation:

```delightql
foo("first", 2; "second", 20)(*)
```

which sugars explicit anonymous tables:

```delightql
foo(_("first", 2; "second", 20))(*)
```

but still allows pipe invocation:

```delightql
two_column_table(*)
  |> foo(*)
```

Or explicit functor invocation:

```delightql
foo(two_column_table(*))(*)
```

Scalar lifting requires a positional contract – an inner glob functor cannot accept inline scalars because there is no declared arity to match against.

3.2.4.3. The & Rule

& is required only when using scalar lifting with an argumentative functor alongside other parameters.

When every table argument is passed as a functor expression, the parentheses disambiguate each argument. Commas separate parameters as usual – no & needed. & is the cost of the scalar-lifting shorthand: when bare scalars fill an argumentative functor, & marks where one argument ends and the next begins.

Definition	Functor call site	&?
`f(T(*), V(*))`	`f(users(*), orders(*))(*)`	no
`f(T(*), V(*))`	`users(*) |` `> f(orders(*))(*)`	no
`f(T(*), n)`	`f(users(*), 10)(*)`	no
`f(T(*), V(*), n)`	`f(users(*), orders(*), 10)(*)`	no
`f(T(x, y))`	`f(data(col1, col2))(*)`	no
`f(T(x, y))`	`f(_(1, 2; 10, 20))(*)`	no
`f(T(x, y))`	`_(1, 2; 10, 20) |` `> f(*)`	no
`f(T(*), V(x, y))`	`f(users(*), _(1, 2))(*)`	no
`f(T(*), V(x, y))`	`f(users(*), data(col1, col2))(*)`	no
`f(T(*), V(x, y))`	`users(*) |` `> f(_(1, 2))(*)`	no
`f(T(*), V(x, y), n)`	`f(users(*), _(1, 2), 10)(*)`	no
`f(T(*), V(x, y), n)`	`f(users(*), _(1, 2; 10, 20), 10)(*)`	no
`f(::ns, n, V(x, y))`	`f(data::prod, "t", _(1, 2))(*)`	no
Scalar lifting (shorthand)		
`f(T(x, y))` (single)	`f(1, 2)(*)`	no
`f(T(x, y))`	`f(1, 2; 10, 20)(*)`	no
`f(T(*), V(x, y))`	`f(users(*) & 1, 2)(*)`	yes
`f(T(*), V(x, y))`	`f(users(*) & 1, 2; 10, 20)(*)`	yes
`f(T(x, y), n)`	`f("a", "b" & 10)(*)`	yes
`f(T(x, y), V(a, b))`	`f(1, 2 & 3, 4)(*)`	yes
`f(::ns, n, V(x, y))`	`f(data::prod & "t" & 1, 2)(*)`	yes

The table is divided into two regions. In the top region, every table argument uses functor syntax – `&` is never needed. In the bottom region (scalar lifting), bare scalars fill argumentative functors and `&` marks the boundaries.

Functor syntax is always available and always unambiguous. Scalar lifting is an optional shorthand for inline data – use `&` when you use it, or wrap in `_()` to avoid it.

3.2.4.4. Parameter Grounding and Multi-Clause HO Entities

The two parentheses partition a single relation into "positions the caller sets" and "columns the body produces." Both sets follow the same head semantics (see Head Semantics), applied independently.

First parentheses: always argumentative. The parameter parentheses must explicitly declare parameters.

Second parentheses: any head form. The output parentheses follow all standard head rules: glob or argumentative, consistent across clauses, smart union corresponding for globs, strict positional+name agreement for argumentative.

3.2.4.4.1. Parameter modes

Table parameters are input-moded – they must be grounded because the body computes over them. There is no way to enumerate "all tables." Scalar parameters are bidirectional – they can be grounded (filter to matching clauses) or left free (project as a column).

Parameter kind	Mode
Scalar	bidirectional
Table	input-only

A scalar parameter can be left free (unbound at the call site) only when every clause has a ground term at that position.

delightql

```
schema("employees")(name, type) :-
  _(name, type ---- "id", "INT"; "name", "TEXT")
schema("departments")(name, type) :-
  _(name, type ---- "dept_id", "INT"; "dept_name",
"TEXT")
```

The ground constants define the enumeration domain: `schema(entity)(*)` enumerates `"employees"` and `"departments"` at the parameter position because those are the constants in the clauses.

If any clause has a free variable at that position, the caller must provide a concrete value – either a literal or a variable bound from context (a pipe, CTE, join, etc.).

3.2.4.4.2. Scalar parameters as discriminators

When a higher-order entity has multiple clauses with different ground scalar values in a parameter position, invocation with a matching ground term selects the relevant clauses. This is clause selection via equality – the same mechanism as argumentative grounding.

```delightql
schema("employees")(name, type) :-
  _(name, type ---- "id", "INT"; "name", "TEXT")
schema("departments")(name, type) :-
  _(name, type ---- "dept_id", "INT"; "dept_name",
"TEXT")
```

Grounded query – filter:

```delightql
schema("employees")(*)
```

The ground term `"employees"` selects the matching clause. Output: `(name, type)` – two columns. The ground parameter filters but does not project.

Free query – project:

```delightql
schema(entity)(*)
```

The first position is free. All clauses contribute (UNION ALL). The free parameter appears as a column:

```
entity      | name     | type
------------|----------|--------
employees   | id       | INT
employees   | name     | TEXT
departments | dept_id  | INT
departments | dept_name| TEXT
```

This is the same behavior as argumentative grounding on regular relations where `stock_ownership(1, stock_id, ...)` filters on position 1 and drops it from the output.

3.2.4.4.3. Mixed ground/free across clauses

The same scalar position can be ground in some clauses and free in others. This follows standard relational semantics: every clause that matches contributes rows.

```delightql
foo("a", y)(*) :- ...   -- pos 1 ground, pos 2 free (parameter)
foo("b", y)(*) :- ...   -- pos 1 ground, pos 2 free (parameter)
foo(x, "c")(*) :- ...   -- pos 1 free (parameter), pos 2 ground
```

Invocation:

```delightql
_(z ---- "c"; "d"; "e") |> foo("a", z)(*)
```

For each row, both positions are concrete. Each clause either matches or doesn't:

- Clause 1: `"a"` matches `"a"`, `y` binds to `z`. **Selected.**
- Clause 2: `"a"` doesn't match `"b"`. **Excluded.**
- Clause 3: `x` binds to `"a"`, `z` must equal `"c"`. **Selected for that row only.**

There is no ambiguous dispatch. The relational world has no "which clause wins?" conflict – every matching clause contributes rows.

3.2.5. Sigma Rules

Sigma rules encapsulate reusable boolean logic:

```delightql
is_high_value(amount) :- amount > 1000
```

```delightql
orders(*),
  +is_high_value(total),
  +like(description, '%ipod')
```

Disjunctive Clauses

Multiple clauses with the same head are OR-ed together:

```delightql
no_data("NA"; "N/A"; "UNKNOWN")

empty(column) :- null = column
empty(column) :- trim:(column) = ""
empty(column) :- +no_data(upper:(column))
```

delightql
```
employee(*),
  +empty(LastName),
  +empty(FirstName)
```

SQL
```
SELECT *
FROM employee
WHERE (LastName IS NULL
       OR trim(LastName) = ''
       OR upper(LastName)
        IN ('NA', 'N/A', 'UNKNOWN'))
  AND (FirstName IS NULL
       OR trim(FirstName) = ''
       OR upper(FirstName)
        IN ('NA', 'N/A', 'UNKNOWN'));
```

Requirements.

To create a sigma rule:

- The head is a relational functor with arguments
- The neck is `:-`
- The body consists of conjoined sigma predicates
- Each parameter must appear at least once in the body
- In disjunctive form, each clause must reference at least one parameter

> Sigma predicates include:
>
> - Infix comparisons: `age < 20`, `LastName = 'Johnson'`
> - Functor predicates: `+like(description, 'ipod%')`, `+between(Salary, 50000, 100000)`
> - `in` statements: `state in ("MA"; "TX"; "CA")`
> - Existence tests: `+other_table(...)`, `\+other_table(...)`

3.2.6. ER-Context Rules

ER-context rules are an answer to the question: what if we could define entity relationships that inform queries?

Normalized schemas encode relationships with foreign keys but query expressions do not take advantage of this. SQL requires repeating join conditions in every query – unaware of DDL constraints.

ER-context rules define these relationships once. The `&` and `&&` operators reference them concisely.

3.2.6.1. Defining Relationships

An ER-rule declares how two tables join. The head uses `&` between table names; the body is the join expression:

```delightql
users&orders(*) within normal :-
  users(*), orders(*), users.id = orders.user_id

orders&items(*) within normal :-
  orders(*), items(*), orders.id = items.order_id

items&products(*) within normal :-
  items(*), products(*), items.product_id = products.id
```

The `within` clause assigns the rule to a named context.

3.2.6.2. Multiple Contexts

The same table pair can have different join semantics in different contexts:

```delightql
users&orders(*) within normal :-
  users(*), orders(*), users.id = orders.user_id

users&orders(*) within audit :-
  users(*), orders(*), users.id = orders.created_by

orders&audit_log(*) within audit :-
  orders(*), audit_log(*), orders.id =
audit_log.order_id
```

The context name is any valid identifier.

3.2.6.3. Using Contexts

The `under` directive activates a context. It must be the first token in the query:

```delightql
under normal: users(*) & orders(*)

under audit: users(*) & orders(*)
```

The directive applies to the entire query scope. Mixing contexts in one query is not permitted.

3.2.6.4. Direct Join (&)

The `&` operator performs a direct lookup in the current context:

```delightql
under normal: users(*) & orders(*)
```

Equivalent to:

```delightql
users(*), orders(*), users.id = orders.user_id
```

Multiple `&` operators chain left-to-right. Each consecutive pair must have a defined ER-rule:

```delightql
under normal: users(*) & orders(*) & items(*)
```

Compiles to:

```delightql
users(*), orders(*), items(*),
  users.id = orders.user_id,
  orders.id = items.order_id
```

3.2.6.5. Transitive Join (&&)

The `&&` operator finds a path through the ER-graph:

```delightql
under normal: users(*) && products(*)
```

No direct `users&products` rule exists, but the path does: `users -> orders -> items -> products`.

Ambiguity is an error. If multiple paths exist, the query fails:

```delightql
users&orders(*) within normal :- ...
orders&items(*) within normal :- ...
users&items(*) within normal :- ...   // creates a cycle

under normal: users(*) && items(*)
// Error: Ambiguous join path from 'users' to 'items':
//   Path 1: users -> orders -> items
//   Path 2: users -> items (direct)
```

3.3. RECURSION IN RULES

Recursion in delightql emerges from self-reference. When a predicate's definition includes a clause that references

the predicate itself, the definition is recursive. When a common table expression includes a clause that references the CTE itself, the CTE is recursive. Both transpile to SQL's `WITH RECURSIVE` construct.

This chapter covers the semantics of recursion in delightql, how it maps to SQL's execution model, and the constraints that model imposes.

3.3.1. Two Forms of Recursion

Delightql supports recursion in two contexts:

Recursive rules are defined in assertion mode and persist as reusable predicates:

```delightql
ancestor(person, anc) :-
  parent(person, anc)
ancestor(person, anc) :-
  parent(person, p), ancestor(p, anc)
```

Recursive CTEs are defined inline in query mode, scoped to a single query:

```delightql
ancestor(*) : parent(*) |> (person, parent as anc)
ancestor(*) : parent(*) as p, ancestor(*) as a, p.parent
= a.person
    |> (p.person, a.anc)
ancestor(*)
```

Both forms transpile to `WITH RECURSIVE`. The choice depends on whether the recursive logic is reusable (rule) or ad-hoc (CTE).

3.3.2. The Anatomy of Recursion

Every recursive definition has two components:

Base clauses provide initial rows without self-reference. These are SQL's "anchor members":

```delightql
_(n @ 1) : counter                    // literal base
case
org(*), title = "CEO" : mgmt          // filtered base
case
edge(*) |> (origin, dest) : reachable // projected base
case
```

Recursive clauses reference the predicate or CTE being defined. These are SQL's "recursive members":

```delightql
counter(*), n < 100 |> (n + 1 as n) : counter
mgmt(*) as m, org(*) as o, o.boss = m.name : mgmt
reachable(*) as r, edge(*) as e, r.dest = e.origin
    |> (r.origin, e.dest) : reachable
```

Delightql does not require base clauses to precede recursive clauses in source order. The transpiler identifies which clauses are recursive (they reference the target name) and emits them in the order SQL requires.

3.3.3. Evaluation Model

SQL's recursive CTEs evaluate using a **working table** algorithm:

1. Execute all base clauses; their results form the initial working table
2. Execute the recursive clause with the working table as input
3. The output becomes the new working table
4. Repeat until the working table is empty
5. Return the union of all iterations

This is **bottom-up** or **co-recursive** evaluation: starting from known facts, derive new facts, repeat until fixed point. It resembles dynamic programming more than classical recursion.

The critical implication: **the recursive clause sees only the previous iteration's rows, not the full accumulated result**. This is why certain operations are prohibited – they would require access to rows that haven't been computed yet or have already been consumed.

3.3.4. What Recursion Can Express

SQL's recursive model handles a well-defined class of problems:

Hierarchical traversal – org charts, bill of materials, folder structures:

```delightql
folders(*), parent_id = null |> (id, name, 0 as depth) :
tree
folders(*) as f, tree(*) as t, f.parent_id = t.id
    |> (f.id, f.name, t.depth + 1) : tree
tree(*)
```

Transitive closure – reachability, ancestry, dependency graphs:

```delightql
edge(*) |> (origin, dest) : reachable
reachable(*) as r, edge(*) as e, r.dest = e.origin
    |> (r.origin, e.dest) : reachable
reachable(*) |> %(*)  // deduplicate
```

Sequence generation – numeric ranges, date series, iteration:

```delightql
_(d @ date:(2024, 1, 1)) : dates
dates(*), d < date:(2024, 12, 31)
    |> (d + interval:(1, 'day') as d) : dates
dates(*)
```

Iterative computation – any algorithm expressible as "given previous state, compute next state":

```delightql
_(iter @ 0, x @ 1.0, target @ 2.0) : newton
newton(*), abs:(x*x - target) > 0.0001, iter < 100
    |> (iter + 1, (x + target/x) / 2.0 as x, target) :
newton
newton(*) |> %(target ~> max:(x) as sqrt)
```

3.3.5. What Recursion Cannot Express

The working-table model imposes fundamental limitations. These are not arbitrary restrictions – they follow from the evaluation semantics.

3.3.5.1. No Aggregation in Recursive Clauses

Aggregation requires access to multiple rows. The recursive clause sees only the working table (previous iteration), not the full accumulated result.

```delightql
// INVALID -- cannot aggregate within recursion
subtree(*) as s, node(*) as n, n.parent = s.id
    |> (n.id, s.total + n.value as total) : subtree  //
seems ok?

// But this fails:
subtree(*) as s, node(*) as n, n.parent = s.id
    ~> (s.id, sum:(n.value) as total) : subtree  //
aggregation -- NOT ALLOWED
```

3.3.5.2. No Subqueries Referencing the Recursive Target

A subquery inside the recursive clause cannot reference the CTE being defined:

```delightql
// INVALID -- subquery references 'paths'
edge(*) as e, paths(*) as p, e.origin = p.dest,
    \+ paths(*, e.dest = dest)  // "dest not already
reached" -- NOT ALLOWED
    |> (p.origin, e.dest) : paths
```

The subquery `paths(*, ...)` would need to see all accumulated rows, which aren't available.

3.3.5.3. No Mutual Recursion

Two predicates cannot reference each other:

```delightql
// INVALID -- mutual recursion
even(0)
even(n) :- odd(m), n = m + 1
odd(n) :- even(m), n = m + 1
```

SQL's `WITH RECURSIVE` processes one CTE at a time. There's no mechanism for two CTEs to co-evolve.

3.3.5.4. Single Self-Reference

The recursive clause may reference the target exactly once:

```delightql
// INVALID -- two self-references
paths(*) as p1, paths(*) as p2, p1.dest = p2.origin
    |> (p1.origin, p2.dest) : paths
```

This would require joining the working table against itself, which SQL doesn't support in recursive CTEs.

3.3.6. Termination

Recursive CTEs terminate when the recursive clause produces no new rows. This happens when:

- A `WHERE` condition filters out all candidates
- A join finds no matches
- The depth limit (`#`) is reached
- The data is exhausted (finite traversal)

Ensuring termination:

For sequence generation, always include a bound:

```delightql
nums(*), n < 1000 |> (n + 1 as n) : nums  // terminates at 1000
```

For graph traversal over potentially cyclic data, track visited nodes:

```delightql
edge(*) |> (origin, dest, ',' || origin || ',' as visited) : paths
edge(*) as e, paths(*) as p, p.dest = e.origin,
    p.visited not like '%,' || e.dest || ',%'
    |> (p.origin, e.dest, p.visited || e.dest || ',') : paths
```

For unknown depth, use `#` as a safety limit:

```delightql
tree(*) as t, node(*) as n, n.parent = t.id, # < 100
    |> (...) : tree
```

3.3.7. UNION vs UNION ALL

By default, delightql emits `UNION ALL` – duplicates across iterations are preserved. This is efficient and correct for most traversals.

For graph traversal where the same node may be reached via multiple paths, duplicates accumulate. To deduplicate the final result:

```delightql
edge(*) |> (origin, dest) : reachable
edge(*) as e, reachable(*) as r, r.dest = e.origin
    |> (r.origin, e.dest) : reachable
reachable(*) |> %(*)  // deduplicate at the end
```

3.3.8. Higher-Order Recursive Predicates

Recursive rules can be parameterized, deferring the base case:

```delightql
reports_to(boss)(name) :- employee(*), name = boss.
reports_to(boss)(name) :-
    employee(*) as e,
    reports_to(boss)(*) as r,
    e.manager = r.name
    |> (e.name).
```

Each invocation monomorphizes to a concrete `WITH RECURSIVE`:

```delightql
reports_to("Alice")(*)  // who reports to Alice?
reports_to("Bob")(*)    // who reports to Bob?
```

The higher-order parameter `boss` is inlined into the anchor clause at query time. The recursive structure itself doesn't change – only the starting point.

3.3.9. Example: Mandelbrot Set

This example demonstrates sequence generation, computational iteration, and post-recursion aggregation working together:

```delightql
_(x@-2.0)                                    : xaxis
xaxis(*), x < 1.2
 |> (x + 0.05 as x)                          : xaxis
_(y@-1.0)                                    : yaxis
yaxis(*), y < 1.0
 |> (y + 0.1 as y)                           : yaxis
sq:(x):
  x * x
xaxis(*), yaxis(*)
 |> (0 as iter,
     x as cx,
     y as cy,
     0.0 as x,
     0.0 as y)                               : m
m(*), (sq:(x) + sq:(y)) < 4.0,
  iter < 28
 |> (iter + 1 as iter,
     cx as cx,
     cy as cy,
     (sq:(x) - sq:(y)) + cx as x,
     ((2.0 * x) * y) + cy as y)              : m
m(*)
 |> %(cx,cy ~> max:(iter) as iter )          : m2
m2(*)
 |> %(cy
       ~>
     group_concat:(substr:(" .+*#", 1+min:(iter/7,4), 1), "") as t)
                                             : a
a(*)
 ~> group_concat:(rtrim:(t),char:(0x0a))
```

The query generates a coordinate grid, runs the escape-time algorithm via recursive iteration, then aggregates the results into ASCII art – all in a single delightql expression.

3.3.10. Delightql Recursive Apology

A true fixed-point engine – like those in Datalog systems – would maintain the full set of derived facts and allow each iteration to query against it. SQL chose a simpler model. The restrictions on aggregation, subqueries, and mutual recursion all follow from this choice.

Delightql inherits these limitations because it transpiles to SQL and the semantics remain bound by the target. Where SQL's recursive CTEs fall short – self-similar tree construction, recursive aggregation, shortest-path computation – delightql falls short as well.

3.4. FUNCTION RULES

Functions are relations with a **functional dependency** between input and output columns. Where a relation may have many outputs for a given input, a function has exactly one. Delightql supports several syntactic forms for defining functions, each suited to different use cases.

3.4.1. Stacked Notation (Named Case)

The stacked form defines functions as lookup tables with explicit input-output mappings:

```delightql
department_kind(
  department     -> kind
  ------------------
  "engineering"  -> "tech";
  "data science" -> "tech";
  _              -> "other"
)
```

The -> separates inputs (left) from outputs (right). The header row names the columns; subsequent rows provide the mappings. The _ matches any input not explicitly listed.

Despite the visual similarity to anonymous table stacked notation, this is an assertion-mode construct – it defines a reusable function, not inline data.

Invocation:

```delightql
employee(*) |> +(department_kind:(Department) as kind)
```

```SQL
SELECT *,
  CASE Department
    WHEN 'engineering' THEN 'tech'
    WHEN 'data science' THEN 'tech'
    ELSE 'other'
  END AS kind
FROM employee;
```

Multi-column inputs:

```delightql
tax_rate(
  state, category -> rate
  -------------------------
  "CA", "food"     -> 0.0;
  "CA", "electronics" -> 0.0825;
  "TX", "food"     -> 0.0;
  "TX", "electronics" -> 0.0625;
  _, _             -> 0.05
)
```

```delightql
products(*) |> +(tax_rate:(state, category) as tax)
```

3.4.2. Rule Form

For computed functions, use the rule form:

```delightql
plus_two:(x) :- x + 2
```

```delightql
numbers(*) |> +(plus_two:(value) as incremented)
```

```sql
SELECT *, value + 2 AS incremented FROM numbers;
```

The body is any domain expression. The function returns its evaluation.

3.4.3. Disjunctive Clauses

Multiple clauses create conditional functions. Clauses are evaluated top-to-bottom; first match wins:

```delightql
fizzbuzz:(n | n % 15 = 0) :- "fizzbuzz"
fizzbuzz:(n | n % 3 = 0)  :- "fizz"
fizzbuzz:(n | n % 5 = 0)  :- "buzz"
fizzbuzz:(n)              :- n
```

The guard condition follows | in the head. If the guard fails, the next clause is tried.

```delightql
generate_series(1, 100)(*) |> (fizzbuzz:(value) as
result)
```

```sql
SELECT
  CASE
    WHEN value % 15 = 0 THEN 'fizzbuzz'
    WHEN value % 3 = 0 THEN 'fizz'
    WHEN value % 5 = 0 THEN 'buzz'
    ELSE CAST(value AS TEXT)
  END AS result
FROM generate_series(1, 100);
```

Hailstone sequence example:

```delightql
next_hailstone:(x | x % 2 = 0) :- x / 2
next_hailstone:(x)             :- (x * 3) + 1
```

3.4.4. Composition Notation

Point-free function composition uses the F-PIPE sigil:

```delightql
clean:(@) :- trim:() /-> upper:()
```

Equivalent to:

```delightql
clean:(x) :- upper:(trim:(x))
```

The piped form reads left-to-right, matching data flow.

With placeholder:

```delightql
birth_year:(@) :- strftime:("%Y", @) /-> cast:(@ as
int)
```

The `@` marks where the piped value is inserted when the function takes multiple arguments.

3.4.5. Higher-Order Functions

Functions are inherently higher-order: any function can accept other functions as parameters. Mark function parameters with colon-functor syntax `f:()` in the signature to distinguish them from scalar parameters:

```delightql
apply:(f:(), x) :- f:(x)
```

The `f:()` declares that the first parameter is a function. The body calls whatever function was passed in. Scalar parameters are bare names as usual.

Invocation:

```delightql
users(*) |> (apply:(upper:(), first_name) as formatted)
```

The call site passes `upper:()` (a curried function) and `first_name` (a column) as two arguments. Arity matching works the same as regular functions: `apply` has arity 2, and the call provides 2 arguments.

Multiple function parameters:

```delightql
chain:(f:(), g:(), x) :- x /-> f:() /-> g:()
```

```delightql
users(*) |> (chain:(upper:(), trim:(), first_name) as cleaned)
```

Lambda as function argument:

```delightql
apply_twice:(f:(), x) :- x /-> f:() /-> f:()
```

```delightql
users(*) |> (apply_twice:(:(@ * 2), age) as quadrupled)
```

Mixed function and scalar parameters:

```delightql
transform_and_compute:(f:(), g:(), value, multiplier) :-
  f:(value) /-> g:() /-> :(@ * multiplier)
```

With conditional logic:

```delightql
apply_if_long:(f:(), value) :-
  _:(length:(value) > 5 -> f:(value); _ -> value)
```

No double parentheses. Unlike higher-order views, higher-order functions use a single set of parentheses. Views need double parens because they operate on two modal categories – input-only parameters (tables) and bidirectional columns. Functions have no such distinction: everything is a value in, scalar out. See Higher-Order Rules for the full rationale.

3.4.6. Contextual Functions

The `..` sigil indicates a function that captures variables from its invocation context:

delightql
```
excess_index:(..) :-
  (1 + total - (interest_rate / 252))
    /-> greatest:(0.01)
    /-> ln:()
    /-> :(@ * 2)
    /-> sum:(<~ #(date))
    /-> exp:()
```

delightql
```
prices(*) |> (excess_index:(..) as idx)
```

The function analyzes its body for free variables (`total`, `interest_rate`, `date`) and expects them from the calling relation. This is structural typing for functions – any relation with those columns can use the function.

Mixed parameters:

Combine context capture with explicit arguments:

delightql
```
scaled_index:(.., scale_factor) :-
  (1 + total - (interest_rate / 252))
    /-> greatest:(0.01)
    /-> ln:()
    /-> :(@ * scale_factor)
    /-> exp:()
```

delightql
```
prices(*) |> (
  scaled_index:(.., 2) as double_scaled,
  scaled_index:(.., 0.5) as half_scaled
)
```

Named context:

Explicitly declare captured variables:

delightql
```
scaled_index:(..{total, interest_rate}, scale_factor) :-
  (1 + total - (interest_rate / 252))
    /-> greatest:(0.01)
    /-> :(@ * scale_factor)
    /-> exp:()
```

This makes dependencies visible in the signature and allows overriding context with explicit values:

delightql
```
prices(*) |> (
  scaled_index:(.., 2) as from_context,
  scaled_index:(manual_total, manual_rate, 2) as
explicit
)
```

3.4.7. Fact Form

Individual facts define point mappings:

```delightql
department_kind:("engineering" -> "tech")
department_kind:("data science" -> "tech")
department_kind:(_ -> "other")
```

This is equivalent to the stacked form but spread across statements. Use it when mappings are added incrementally or loaded from external sources.

3.4.8. Restrictions

- Stacked notation and rule form cannot be mixed for the same function
- Stacked notation and individual facts cannot be mixed for the same function
- Disjunctive clauses (multiple rules with the same head) must be co-located in the source
- Textual order determines evaluation order for disjunctive clauses

3.5. FACTS

Facts are body-less rules that define ground data. In Prolog terms, they represent the extensional (axiomatic) portion of a program – truths asserted without derivation.

3.5.1. Standard Facts

The notation matches Prolog (minus the terminating period):

```delightql
person(0, "Gusti", "Parlor", "gparlor0@phoca.cz")
person(1, "Diane-marie", "McHenry", "dmchenry1@dot.gov")
person(2, "Ced", "Mainds", "cmainds2@goo.ne.jp")
person(3, "Bren", "Berndsen",
"bberndsen3@goodreads.com")
```

Standard facts sharing the same functor name must be co-located – no other definitions may appear between them.

3.5.2. Stacked Facts

Define tabular data with headers:

delightql
```
employee(
  EmployeeId , FirstName     , LastName
  -------------------
  0  , "Gusti"       , "Parlor" ;
  1  , "Diane-marie" , "McHenry" ;
  2  , "Ced"         , "Mainds"
)
```

The syntax mirrors anonymous tables, but anonymous tables are query-mode constructs (inline data) while stacked facts are assertion-mode constructs.

delightql
```
// Anonymous table (query mode)
_(first_name, last_name
  --------------
  "Gusti"       , "Parlor" ;
  "Diane-marie" , "McHenry"
)

// Stacked fact (assertion mode)
names(first_name, last_name
  --------------
  "Gusti"       , "Parlor" ;
  "Diane-marie" , "McHenry"
)
```

3.5.3. Default Implementation as Views

Delightql implements facts as views by default, not tables:

delightql
```
employee(
  EmployeeId , FirstName     , LastName
  -------------------
  0  , "Gusti"       , "Parlor" ;
  1  , "Diane-marie" , "McHenry" ;
  2  , "Ced"         , "Mainds"
)
```

SQL
```
CREATE TEMP VIEW employee AS
  SELECT 0 AS EmployeeId, 'Gusti' AS FirstName, 'Parlor'
AS LastName
  UNION ALL SELECT 1, 'Diane-marie', 'McHenry'
  UNION ALL SELECT 2, 'Ced', 'Mainds';
```

This seems counterintuitive – facts are data, so why not tables? The justification: typical delightql files contain only a

handful of facts (test fixtures, configuration, lookup tables). For small datasets, the difference between a view over literal values and a table with inserted rows is negligible. Views avoid the overhead of table creation and cleanup.

3.5.4. Sparse Stacked Facts

Stacked facts support the same sparse column syntax as anonymous tables. Mark optional columns with `?` in the header, then use `_(col @ val)` fills in data rows:

```delightql
config(
  key, value, description?, deprecated?
  ---------------------------------------
  "timeout",  30 ;
  "retries",  3,   _(description @ "max retry count") ;
  "legacy",   1,   _(deprecated @ "true")
)
```

This is equivalent to the fully-expanded form:

```delightql
config(
  key, value, description, deprecated
  -----------------------------------
  "timeout",  30,   null,               null ;
  "retries",  3,    "max retry count",  null ;
  "legacy",   1,    null,               "true"
)
```

Sparse columns reduce noise in metadata definitions and configuration facts where most rows only set a few optional properties.

3.6. NAMESPACES

Namespaces organize definitions and data. They provide isolation, qualification, and a mechanism for code reuse across databases.

3.6.1. What Namespaces Are

A namespace is a container for entities – tables, views, rules, functions. Every entity lives in exactly one namespace.

Namespaces are hierarchical, separated by `::`:

```delightql
data::production
lib::analytics
scripts::etl
```

Entities within a namespace are accessed with the period `.`:

```delightql
data::production.users(*)
lib::analytics.clean_name:(text)
scripts::etl.daily_load!(*)
```

The `::` separates namespace parts. The `.` separates namespace from entity.

3.6.2. Namespace Types

Namespaces fall into four categories based on what they contain and how they're used.

3.6.2.1. Pure Rules Namespaces

Contain functions, sigma predicates, transpilation rules, and higher-order views with no external references. Portable – they don't depend on any database – but may depend on other pure namespaces.

```delightql
// In lib::string
clean_name:(text) :- text /-> trim:() /-> upper:()
format_email:(name, domain) :- name ++ "@" ++ domain
```

Pure namespaces can be used anywhere. They have no data dependencies to resolve.

3.6.2.2. Derived Rules Namespaces

Contain rules that reference external tables. These namespaces come in two forms:

Groundable – has free variables (unqualified table references):

```delightql
// In lib::analytics (groundable)
young_users(*) :- users(*), age < 30   // 'users' is a
free variable
```

The reference to `users` must be resolved before use. See Grounding.

Pre-grounded – all references are qualified:

```delightql
// In lib::analytics (pre-grounded)
young_users(*) :- data::production.users(*), age < 30
```

No free variables. Ready to use immediately, but tied to a specific data namespace.

3.6.2.3. Data Namespaces

Map to physical database connections. Contain tables and views introspected from the database.

```delightql
mount!("sales.db", "data::sales")
// Now: data::sales.orders(*), data::sales.customers(*)
```

Data namespaces are the ground truth – they hold actual data.

3.6.3. Namespace Classification

A namespace's type is determined by its contents, not its path:

If it contains...	It's classified as...
Only functions, sigma predicates, pure HO-views	Pure
Any rule referencing external tables	Derived

Table 38: Namespace classification by contents

Data namespaces are separate – they're created by `mount!()` and contain database tables, not rules. They're the target of grounding, not the subject.

3.6.4. Conventional Prefixes

By convention, namespace paths indicate their type:

Prefix	Intended for	Typically created by
`data::`	Database connections	`mount!()`
`lib::`	Pure and derived rules	`consult!()`

Prefix	Intended for	Typically created by
`main`	Default working namespace	Implicit

Table 39: Conventional namespace path prefixes

These are conventions only, not constraints. The system determines namespace type by analyzing contents, independent of path.

3.6.5. Built-in Namespaces

Several namespaces exist automatically.

3.6.6. main

The default working namespace for the REPL. When you use the REPL interactively, you're operating in `main`:

```delightql
active_users(*) :- users(*), status = "active"
// Equivalent to: main.active_users(*)
```

When you `engage!()` a namespace in the REPL, you're making its entities available in `main` without qualification.

More generally, every execution context has a working namespace. In the REPL, it's `main`. During `consult!("file.dql", "lib::foo")`, the working context is `lib::foo`–definitions in that file go into `lib::foo`. During `run!("file.dql")`, the working context inherits from the caller.

3.6.6.1. lib::std::prelude

Core pseudo-predicates, universally available. This is a partial list – see [Standard Library Reference] for the complete set.

Pseudo-predicate	Purpose
`mount!()`	Load database connection
`consult!()`	Load DQL rules file
`engage!()`	Enable unqualified access
`part!()`	Remove engaged namespace
`run!()`	Execute query file

Table 40: Core pseudo-predicates in lib::std::prelude

The DML pseudo-predicates (`insert!()`, `update!()`, `delete!()`) are covered in [DML] and [Scripted Mutations].

No explicit engage needed – these are available everywhere.

[36]

36 The pseudo-predicates that load and inspect namespaces are themselves defined in a namespace. This circularity is intentional – the system is self-describing. You can query `sys::entities.entity(*)` to see all built-in entities, including these pseudo-predicates.

3.6.6.2. lib::std::predicates

Built-in sigma predicates, universally available:

```delightql
users(*), +like(name, "A%"), +between(age, 18, 65)
```

See [Standard Library Reference] for the complete list.

3.6.6.3. sys::* (Introspection)

Metadata namespaces for system introspection:

Namespace	Contains
`sys::ns`	Namespaces, engaged relationships, activated entities
`sys::entities`	Entities, types, references, resolutions
`sys::cartridges`	Cartridges, source types, connections

Table 41: System introspection namespaces

Not auto-engaged. Query explicitly when needed:

```delightql
sys::ns.namespace(*)
sys::entities.entity(*), type = 10   // database tables
sys::cartridges.cartridge(*)
```

3.6.7. Pseudo-predicates and “attaching” context

There are several functor forms ending with an exclamation point that are used to bring rules, facts, and data into scope and within a namespace.

3.6.7.1. mount!() – Database Connections

Opens a database and introspects its tables:

```delightql
mount!("sales.db", "data::sales")
```

Side effects:

1. Creates namespace `data::sales`
2. Introspects tables and views
3. Registers entities in namespace

After mounting, tables are accessible:

```delightql
data::sales.orders(*)
data::sales.customers(*)
```

3.6.7.2. consult!() – DQL Rules

Loads a `.dql` file containing rules:

```delightql
consult!("analytics.dql", "lib::analytics")
```

The file contains rule definitions:

```delightql
// analytics.dql
young_users(*) :- users(*), age < 30
high_value(*) :- orders(*), total > 1000
```

Side effects:

1. Creates namespace `lib::analytics`
2. Parses file
3. Creates session views/functions
4. Registers entities in namespace

Rules are now accessible (qualified or via engage):

```delightql
lib::analytics.young_users(*)
```

3.6.7.3. engage!() – Unqualified Access

Makes a namespace's entities available without qualification:

```delightql
engage!("lib::analytics")

// Now can write:
young_users(*)
// Instead of:
lib::analytics.young_users(*)
```

Engaging doesn't load anything – the namespace must already exist.

3.6.7.4. part!() – Remove Engaged Namespace

Removes a namespace from engaged scope:

```delightql
part!("lib::analytics")

young_users(*)                          // Error: not found
lib::analytics.young_users(*)           // Still works
(qualified)
```

3.6.8. Grounding

Groundable namespaces have free variables – references to tables that aren't defined in the namespace. Grounding binds those variables to a data namespace.

3.6.8.1. Formal Rule

In the expression `F^S.e(*)`:

- Only entities of **S** are visible. The entity `e` must be defined in S.
- **F** is never directly accessible. It supplies bindings for free variables inside S's entity bodies.
- Grounding does **not** grant access to S's other entities (e.g., functions defined in S are not made available in pipe expressions). Functions must be accessed via qualification (`S.func:(x)`) or `engage!("S")`.

Put differently: `F^S.e(*)` means "from S, give me `e`, and when `e`'s body references tables, find them in F." It does not mean "merge F and S together."

3.6.8.2. The Problem Again

```delightql
// In lib::analytics (groundable)
young_users(*) :- users(*), age < 30
```

`users` is referenced but not defined. This namespace can't be used until `users` is bound to an actual table.

3.6.8.3. Query-Time Grounding

Use ^ to ground at the point of use:

```delightql
data::production^lib::analytics.young_users(*)
```

This binds `users` to `data::production.users` for this query.

Query-time grounding uses **lazy validation** – only the accessed entity and its dependencies are checked. Other entities in the namespace may have unresolved references; they won't cause failure unless you use them.

```delightql
// lib::analytics has:
//   young_users(*) :- users(*), age < 30       // OK;
users exists in production
//   revenue_report(*) :- sales(*), amount > 0  // FAIL;
sales doesn't exist

data::production^lib::analytics.young_users(*)    // OK
data::production^lib::analytics.revenue_report(*) //
FAIL: sales not found
```

3.6.8.4. Permanent Grounding

Query-time and engage-time grounding are temporary. For a permanent binding, use `ground!()`:

```delightql
ground!(data::production, lib::analytics,
"lib::analytics_prod")
```

All three arguments are required. The first two are namespace paths; the third is a string literal naming the new namespace.

This:

1. Validates **all** entities in `lib::analytics` against `data::production` (strict validation). If any entity has an unresolved table reference, the entire operation fails – nothing is created.
2. Creates a new namespace `lib::analytics_prod`
3. Copies all entities with free variables bound to `data::production`
4. The new namespace is pre-grounded – no ^ operator needed

The result is a new namespace, not a mutation of the original. This prevents stateful bugs and makes the operation idempotent.

3.6.8.5. Chained Grounding

Ground through multiple layers:

```delightql
data::production^lib::base^lib::extended.final_view(*)
```

Each ^ binds the namespace to its right against the accumulated context to its left.

3.6.8.6. Grounding as Inverse Engage

Another way to think about grounding: `engage!()` brings a namespace's entities into your scope; grounding injects bindings into a namespace's scope.

```delightql
// Engage: bring lib::analytics INTO main
engage!("lib::analytics")

// Ground: inject data::production INTO lib::analytics
data::production^lib::analytics
```

Grounding reaches into the groundable namespace and says "when you reference `users`, you mean `data::production.users`."

3.6.8.7. Validation Summary

Operation	Validation	Persistence
`data::ns^lib::ns.entity(*)`	Lazy (just this entity)	Query only
`engage! (data::ns^lib::ns)`	Strict (whole namespace)	Engage scope
`ground!(data, lib, "new")`	Strict (whole namespace)	Permanent (new namespace)

Table 42: Grounding validation summary

3.6.8.8. Constraints

No intersection. The ground namespace and groundable namespace cannot share entity names. If both define `users`, grounding is ambiguous and fails.

Same database technology. Cross-database grounding (e.g., SQLite namespace against PostgreSQL namespace) is not supported.

3.6.9. Imprinting

Session-scoped entities (created with `:-`) disappear when the session ends. Imprinting makes them permanent.

More so than most of what we've discussed before: **this is where actual SQL DDL will be generated**.

3.6.9.1. The Problem

delightql

```
consult!("schema.dql", "lib::schema")
// Creates session views

// Session ends... views are gone
```

3.6.9.2. The Solution

delightql

```
lib::schema(*) |> imprint!(data::production)
```

Imprinting:

1. Validates that all entities can resolve against the target (strict validation)
2. Generates DDL (`CREATE VIEW`, `CREATE TABLE`)
3. Executes DDL on the target database
4. Entities now exist permanently in the data namespace

3.6.9.3. Grounding and Imprinting

Grounding and imprinting are highly related: where grounding proves compatibility, imprinting makes it permanent.

If `data::production^lib::analytics` is valid grounding, then `lib::analytics(*) |> imprint!(data::production)` is valid imprinting. The grounding operation proves that the derived namespace can bind against the data namespace. Imprinting persists that binding.

delightql

```
// 1. Load database
mount!("prod.db", "data::production")

// 2. Load groundable rules
consult!("analytics.dql", "lib::analytics")

// 3. Ground and test (lazy validation)
data::production^lib::analytics.young_users(*) |> count:
(*)

// 4. Commit to grounding (strict validation)
engage!(data::production^lib::analytics) as analytics

// 5. Work confidently
analytics.young_users(*)
analytics.revenue_report(*)

// 6. Persist (strict validation)
lib::analytics(*) |> imprint!(data::production)
```

Steps 4 and 6 both perform strict validation. If engage succeeds, imprint will succeed (assuming no concurrent changes).

4. DATA MANIPULATION LANGUAGE (DML)

Delightql supports SQL's tree mutation operations through four destructively sigilized pipe targets:

- `update!(T(*))(*)` – modify existing rows
- `insert!(T(*))(*)` – add new rows
- `delete!(T(*))(*)` – remove rows
- `keep!(T(*))(*)` – keep rows, deleting others

The `T(*)` is the **mutation target** – a functor expression identifying which relation to mutate.

4.0.1. The `!!` Marker

For `update!`, `delete!`, and `keep!`, the source relation is also the mutation target – the rows being sourced are the rows being mutated. Mark the source with `!!` to make this explicit:

delightql

```
hr.employee!!(*)                    // !! = "these rows
will be mutated"
  , Department = "Executive"
  |> delete!(hr.employee(*))(*)
```

The `!!` marker is required when the source is the mutation target. The compiler verifies that the `!!`-marked relation matches the terminal target.

For `insert!`, the source rows are **read-only input** – even when the source table happens to be the same as the target. Do not use `!!` on insert sources:

delightql

```
employees(*)                        // no !! -- these
rows are read-only
  , department = "Engineering"
  |> (id + 10 as id, name, department, age, salary)
  |> insert!(employees(*))(*)
```

Terminal	Source has `!!`?	Reason
`update!`	Yes	Source rows are modified in place
`delete!`	Yes	Source rows are removed
`keep!`	Yes	Source rows are the universe being pruned
`insert!`	No	Source rows are read-only input

4.1. UPDATE

To update a table, pipe a matching schema into `update!` pseudo-predicate. The name of the table to be updated must be the higher-order parameter – this is the mutation target. [37] The mutation target must be the source of the data as well.

37 Note that this implies that the DML pseudo-predicate accepts two higher-order parameters: the contents of the query before the pipe and the table targeted.

delightql

```
hr.employee!!(*)
  , Department = "Executive"
  |> $$("-------" as ssn)
  |> update!(hr.employee(*))(*)
```

SQL

```
UPDATE hr.employee
SET ssn = '-------'
WHERE Department = 'Executive';
```

4.2. DELETE

To delete from a table, use predication to select the rows that should be removed. The mutation target must also be the source table and the schemas must match.

delightql

```
hr.employee!!(*)
  , Department = "Executive"
  |> delete!(hr.employee(*))(*)
```

SQL

```
DELETE FROM hr.employee
WHERE Department = 'Executive';
```

Without filters, all rows are deleted:

delightql

```
hr.employee!!(*) |> delete!(hr.employee(*))(*)
```

SQL

```
DELETE FROM hr.employee;
```

For convenience, you can use inverted predication and declare which tuples you wish to keep.[38]

38 This is a simple enough rewrite and will be compiled into a delete.

delightql

```
hr.employee!!(*)
  , Department = "Engineering"
  |> keep!(hr.employee(*))(*)
```

4.3. INSERT

Use the `insert!` pseudo-predicate to insert rows. The relation entering the `insert!` pipe must contain a subset of the schema of the mutation target. Any extra or erroneously named columns are an error.

delightql
```
_(LastName, FirstName, age @ "eklund", "daniel", 20)
  |> insert!(employee(*))(*)
```

SQL
```
INSERT INTO hr.employee (LastName, FirstName, age)
VALUES ('eklund', 'daniel', 20);
```

You may union tables and prediacte their tuples to provide input tuples:

delightql
```
hr.employee(*)
  |;| new_hires(*)
  |;| transfers(, effective_date = today:())
  |> insert!(employee(*))(*)
```

delightql
```
candidates(*),
  score > 90 |> (name, Department, start_date)
  |> insert!(hr.employee(*))(*)
```

SQL
```
INSERT INTO hr.employee (name, Department, start_date)
SELECT name, Department, start_date
FROM candidates
WHERE score > 90;
```

5. ANNOTATIONS

Annotations appear at continuation points in a query pipeline, and permit language directives to operate as inline syntactic elements.

5.1. THE ANNOTATION FRAMEWORK

Annotations are distinguished by matching **PARENOTATES** `(~~ ~~)` followed immediately (no space) by an `<identifier>`.

```delightql
(~~<identifier> body ~~)              -- annotation with body
(~~<identifier>:instance body ~~)     -- annotation with instance name
```

The identifier after the `(~~` is the **ANNOTATION-TYPE**.

How the body is parsed within an annotation is a function of the specific **ANNOTATION-TYPE**. Each recognized type has its own grammar rule:

- `(~~assert`: the body is parsed as a DQL continuation
- `(~~error`: no body – just an optional URI which matches with well-known errors
- `(~~danger`: a URI and a toggle state
- `(~~option`: a URI and a toggle state
- `(~~docs`: the body is raw text

A colon form `identifier:instance` names a specific annotation instance and is also a function of the particular annotation type in question.

```delightql
users(*)
  (~~assert:positive_age , age > 0 |> forall(*) ~~)
```

Only the annotation types listed above are recognized by the grammar. Unknown annotation names produce a parse error.

5.2. PLACEMENT

Annotations may appear at any continuation point – before a pipe, before a comma, or at the end of an expression:

```delightql
users(*)
  (~~assert:has_rows |> exists(*) ~~)
  , age > 30
  (~~emit:filtered ~~)
  |> (first_name, email)
```

Annotations are usually transparent to SQL generation and so the pipeline above produces identical SQL to:

```delightql
users(*), age > 30 |> (first_name, email)
```

Multiple annotations at the same point are permitted. They appear as siblings in the CST and are processed in order.

5.3. ANNOTATION TYPES

- `assert` – forks a sub-query, evaluates a predicate, produces a verdict (see **Assertions**)
- `error` – expects compilation to fail, matches the error URI (see **Error Assertions**)
- `danger` – opens or closes a named safety gate for the current query (see **Danger Gates**)
- `option` – selects a strategy or preference for the current query (see **Options**)
- `docs` – attaches documentation to a DDL definition (see **Docs**)

5.4. ASSERTIONS

Assertions verify properties of a relation at a given point in a pipeline. They are annotations whose body is parsed as DQL, using interior relation semantics to scope the current relation.

```delightql
users(*), age > 30
  (~~assert , age > 30 |> forall(*) ~~)
  |> (first_name, email)
```

The assertion above verifies that every row has `age > 30` at that point in the pipeline. The main pipeline is unaffected – the relation after the assertion is the same as before it.

5.4.1. Assertion Syntax

An assertion uses the annotation syntax with the reserved name `assert`:

```delightql
(~~assert <continuation> ~~)
```

The body after `assert` is parsed as a DQL continuation – the same syntax used inside functor parentheses for interior relations (see **Interior Relations**). The `(~~assert` delimiter scopes a sub-query on the current relation. The leading `,` or `|>` is a continuation on the implicit relation, exactly like `users(, age > 20)`.

The sub-query inside the assertion is a **fork**: it branches from the main pipeline, evaluates independently, and the main pipeline continues with the original relation regardless of the assertion's outcome.

The assertion body is pure DQL. It may terminate with an assertion view that produces a single-column, single-row boolean relation (see **Assertion Views** below). If no assertion view is specified, `exists(*)` is implied – the assertion passes if at least one row survives the body's filters:

```delightql
-- these are equivalent
users(*) (~~assert , age > 0 ~~)
users(*) (~~assert , age > 0 |> exists(*) ~~)
```

The bare form is the common case. An explicit view is only needed for `notexists(*)`, `forall(*)`, or `equals(*)`.

5.4.2. Named Assertions

Assertions may carry a name. The name appears after `assert` as a colon-delimited string:

```delightql
(~~assert:"age is positive" , age > 0 |> forall(*) ~~)
(~~assert:"has email" , email != null |> forall(*) ~~)
(~~assert:"at least 3 rows" ~> count:(*) as n, n >= 3 |>
exists(*) ~~)
```

The name should be an author-supplied label that serves as the primary key when recording assertion outcomes. Unnamed assertions still work. They will receive a synthetic key (derived from source location and body hash) but lose cross-run trackability.

5.4.3. Data Assertions

Data assertions check properties of the rows at a point in the pipeline. They end with an assertion view that reduces the relation to a boolean:

```delightql
-- at least one row with age > 20 exists
users(*) (~~assert , age > 20 |> exists(*) ~~)

-- every row has age > 20
users(*) (~~assert , age > 20 |> forall(*) ~~)

-- no nulls in email
users(*) (~~assert , email is null |> notexists(*) ~~)

-- exactly 3 rows
users(*) (~~assert ~> count:(*) as cnt, cnt == 3 |>
exists(*) ~~)

-- id is unique (no duplicates)
users(*) (~~assert ~> %(id ~> count:(*) as n), n > 1 |>
notexists(*) ~~)

-- age is always positive
users(*) (~~assert , age > 0 |> forall(*) ~~)
```

The assertion body is any valid DQL.

5.4.4. Schema Assertions

Schema assertions check structural properties of the relation. They use the meta-ize operator `^` (see **Meta-ize Operator**) to convert the schema to a queryable relation, then apply standard assertions:

```delightql
-- column "age" exists
users(*) |> (name, age)
  (~~assert ^, colname = "age" |> exists(*) ~~)

-- exactly 3 columns
users(*) |> (a, b, c)
  (~~assert ^ ~> count:(*) as n, n == 3 |> exists(*) ~~)

-- no TEXT columns
users(*)
  (~~assert ^, coltype = "TEXT" |> notexists(*) ~~)
```

For exact schema matching, use `equals(*)` with the reverse pipe `<|` (see **Reverse Pipe**) to compare against an expected schema:

```delightql
users(*)
  (~~assert ^ |> equals(*) <| _(colname, colpos
                                ------
                                "age", 1;
                                "last_name", 2;
                                "first_name", 3) ~~)
```

5.4.5. Relational Equality

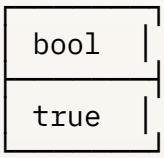
The `equals(*)` view checks bag equality between two relations via the reverse pipe. Bag equality means: same column names in the same order, and the same bag of rows with duplicates and multiplicities preserved.

```delightql
-- assert query result matches expected rows
users(*), age > 50
  (~~assert |> equals(*) <| _(first_name, age
                              ------
                              "Alice", 55;
                              "Bob", 62) ~~)
```

The right operand of `<|` can be any relational expression – a CTE, a table access, or an anonymous table literal.

5.4.6. Assertion Views

Assertion bodies end with a view from `std::prelude` that reduces a relation to a single-row, single-column table. The column is named `bool` and contains `true` or `false`. Every assertion view has this same output shape – the runner reads the `bool` column to determine the verdict.



View	Semantics	SQL pattern
`exists(*)`	At least one row in the input	`SELECT EXISTS(...) AS bool`
`notexists(*)`	No rows in the input	`SELECT NOT EXISTS(...) AS bool`
`forall(*)`	All input rows survived filtering	`SELECT NOT EXISTS(... WHERE NOT ...) AS bool`
`equals(*)`	Bag equality of two relations	

Table 44: Assertion views (auto-imported from std::prelude)

All four views produce the same relation: one row, one column named `bool`. This uniformity means the assertion mechanism needs no special dispatch – the pipeline compiles the body, executes it, and reads `bool` from the single result row.

5.5. ERROR ASSERTIONS

Error assertions verify that a query fails compilation or resolution with a specific error. They use a separate annotation with the reserved name `error`:

```delightql
(~~error://uri/path ~~)
```

The URI identifies the expected error category using a hierarchical path. The pipeline attempts to compile the query; if compilation fails and the actual error matches the URI, the assertion passes.

```delightql
-- should fail: table does not exist
nonexistent_table(*) (~~error://resolution/table_not_
found ~~)

-- should fail: column not in scope
users(*) |> (no_such_column) (~~error://resolution/
column_not_found ~~)

-- should fail: any validation error (prefix match)
users(*), age in (1,2,3) (~~error://validation ~~)
```

A bare error annotation with no URI matches any error:

```delightql
-- should fail with some error, don't care which
bad_query(*) (~~error ~~)
```

Errors are rarely needed for end users.

5.5.1. URI Prefix Matching

The URI is matched as a prefix against the actual error's canonical URI. `error://resolution` matches `resolution/table_not_found`, `resolution/column_not_found`, and any future `resolution/*` error. `error://validation/arity` matches only `validation/arity` and its sub-paths.

5.5.2. Error URI Categories

Each `DelightQLError` variant maps to a canonical URI path. The URI is a stable identifier for the error category, reusable in documentation, tooling, and diagnostics.

URI	Phase	Meaning
`parse`	compile	Syntax-level parse failure
`resolution/table_not_found`	compile	Table not in schema
`resolution/column_not_found`	compile	Column not in scope
`validation/arity`	compile	Wrong number of arguments
`validation/ambiguous`	compile	Ambiguous column reference
`validation/duplicate`	compile	Duplicate name or definition
`build/*`	compile	AST construction errors
`transform/*`	compile	SQL generation errors

URI	Phase	Meaning
`limitation/*`	compile	Known limitations
`runtime/bug`	runtime	Generated SQL rejected by backend (compiler defect)
`runtime/collision`	runtime	Namespace or resource already exists (duplicate mount!/consult!)
`runtime/useafterfree`	runtime	Accessing parted or unavailable resource (use after part!)
`runtime/assertion`	runtime	Data assertion verdict is fail

Table 45: Error URI categories

5.5.3. Coexistence with Data Assertions

Error assertions and data assertions can appear in the same file, documenting both correct and incorrect forms:

```delightql
-- correct: semicolons produce a single-column multi-row relation
users(*), age in (1;2;3)
  (~~assert , age > 0 |> exists(*) ~~)

-- incorrect: commas produce a multi-column single-row relation
users(*), age in (1,2,3) (~~error://validation ~~)
```

5.5.4. Scope

Error assertions are primarily a language development tool. They assert contracts about the compiler's behavior. End users writing queries against a database should have no use for expected failures. [39]

39 I think

5.6. DANGER GATES

Certain behaviors are safe in most contexts but dangerous in others. Rather than forbid them outright, delightql gates them behind danger URIs: named safety boundaries that are closed by default and opened explicitly per-query.

5.6.1. Syntax

A danger gate is a `danger://` URI inside annotation delimiters:

```delightql
employee(*) as e (~~danger://dql/cardinality/nulljoin
ON~~),
  department(*) as d,
  e.DepartmentId = d.DepartmentId
```

The annotation attaches at a continuation point (after a relation). The URI identifies the specific danger. The toggle controls it:

Toggle	Meaning
`ON`	Enable the dangerous behavior for this query
`OFF`	Restore the safe default (useful to override a CLI baseline)
`1`–`9`	Graduated severity levels for host-defined behavior

A bare form without a toggle is an error:

```delightql
// INVALID: no toggle
(~~danger://dql/cardinality/nulljoin~~)
```

5.6.2. Scoping

A danger gate opens for one query and auto-closes at query end. It does not leak into subsequent queries:

```delightql
-- gate is open for this query
employee(*) as e (~~danger://dql/cardinality/nulljoin
ON~~),
  department(*) as d,
  e.DepartmentId = d.DepartmentId

-- gate is closed again -- safe defaults restored
employee(*) as e, department(*) as d,
  e.DepartmentId = d.DepartmentId
```

Multiple gates may be opened for the same query:

```delightql
employee(*) as e
  (~~danger://dql/cardinality/nulljoin ON~~)
  (~~danger://dql/cardinality/cartesian ON~~),
  department(*) as d
```

5.6.3. Session Baseline

The program starts with every danger OFF. A client to the program, lik the CLI, can shift the baseline for guardrail dangers – those that control execution policy (resource limits, safety checks) rather than language semantics:

```
dql query --danger dql/cardinality/cartesian=ON --db
test.db "..."
```

Dangers that change language semantics (what operators mean) cannot be overridden from the CLI. They must appear in the source text – either as inline per-query annotations.

Per-query annotations override the session baseline. At query end, the danger reverts to the enclosing scope:

5.6.4. Danger URI Reference

The full hierarchy of danger URIs, their defaults, and their semantics is documented in the **Danger URI Taxonomy** appendix. The initial dangers are:

URI	What it gates
`dql/cardinality/nulljoin`	NULL-matching joins (= compiles to `IS NOT DISTINCT FROM` in join position)
`dql/cardinality/cartesian`	Cross joins without explicit conditions
`dql/termination/unbounded`	Recursive CTEs without termination conditions

5.7. OPTION ANNOTATIONS

Where danger gates control safety (off by default, opened to permit risky behavior), option annotations control preferences – which code path the compiler uses when multiple paths lead to the same result. A query with an option annotation produces the same logical result regardless of the option state; only the implementation strategy may differ.

Options may be used for non-query reasons too.

5.7.1. Syntax

An option annotation is an `option://` URI inside annotation delimiters:

```delightql
users(*) (~~option://generation/rule/inlining/view ON~~)
|> (id, first_name)
```

The toggle values are identical to danger gates:

Toggle	Meaning
`ON`	Enable the strategy for this query
`OFF`	Disable the strategy (restore default)
`1`–`9`	Graduated preference levels

5.7.2. Scoping

Like danger gates, option annotations are scoped to a single query and auto-revert at query end. Multiple option annotations may appear on the same query.

5.7.3. Session Baseline

The CLI can shift the baseline for a session:

```
dql query --option generation/rule/inlining/view=ON --
db test.db "..."
```

Per-query annotations override the session baseline.

5.7.4. Known Options

URI	Default	What it controls
`generation/rule/inlining/view`	OFF	View inlining strategy during SQL generation
`generation/rule/inlining/fact`	OFF	Fact inlining strategy during SQL generation

5.8. DOCS

Definitions may carry structured documentation between the neck and the body. The docs block uses the annotation delimiters with the `docs` identifier:

```
<HEAD>  <NECK>  (~~docs ... ~~)  <BODY>
```

5.8.1. Syntax

```
high_paid_employees(*) :-
  (~~docs
    Employees with salary above the company median.

    Returns:
      columns: inherited from employee
      cardinality: variable
  ~~)
  employee(*), Salary > 50000
```

The docs block is a `(~~docs ... ~~)` annotation. The body is raw text – no DQL parsing is applied. Line breaks, indentation, and blank lines are preserved as written.

The block must appear immediately after the neck, before the first expression of the body. Only one docs block per definition is permitted.

5.8.2. Applicability

The docs block is valid on any rule-form definition:

Views:

```
active_users(*) :-
  (~~docs
    Users whose account status is active.
  ~~)
  users(*), status = 'active'
```

Functions:

```
tax_amount:(price, rate) :-
  (~~docs
    Computes tax as price times rate, rounded to two
decimal places.

    Returns:
```

```
      type: numeric
  ~~)
  round:(price * rate, 2)
```

Higher-order rules:

```
same_schema(T(*), V(*))(*) :-
  (~~docs
    Compares T's and V's schema for
    equality. Equality is reached if the
    column names match exactly and are
    in the same ordinal position.

    Returns:
      column: pass
      column type: boolean
      cardinality: 1
  ~~)
  first_md(*)  : T(?)
  second_md(*) : V(?)
  together(*)  :
    second_md(*),
      first_md(*.(column_name, ordinal))
  together(~> count:() as a),
    first_md(~> count:() as b),
    second_md(~> count:() as c)
      |> ( (a == b) and (b == c) as pass)
```

Sigma predicates:

```
+is_recent(threshold) :-
  (~~docs
    Filters to rows where created_at is
    within threshold days of today.
  ~~)
  created_at > date:('now', '-' ++ threshold ++ '
days')
```

The docs block is not valid on facts (which have no neck) or on shadow-neck definitions (which are query-scoped and ephemeral).

5.8.3. Storage

When a definition is loaded via `consult!()`, the docs text is extracted at parse time and stored alongside the entity in the system catalog.

The docs are queryable through the system metadata:

```
sys::entities.entities(*)
  |> ( name, doc )
```

6. APPENDIX: TREE NORMAL FORM

Tree grouping bridges two worlds: the relational (flat, tabular, join-oriented) and the hierarchical (nested, tree-structured, document-oriented). Not all JSON has a sensible relational interpretation – arbitrary nesting can be too irregular to map cleanly. But some trees do, and understanding which ones helps clarify what tree grouping actually computes.

This appendix defines tree normal forms – a vocabulary for describing JSON structure and its relational interpretation. Unlike database normal forms (which form a linear hierarchy), tree normal forms are organized as a graph. Nodes are forms; edges are constraints or interpretations. Some edges restrict structure; others assign meaning to nesting.

6.0.1. The Graph

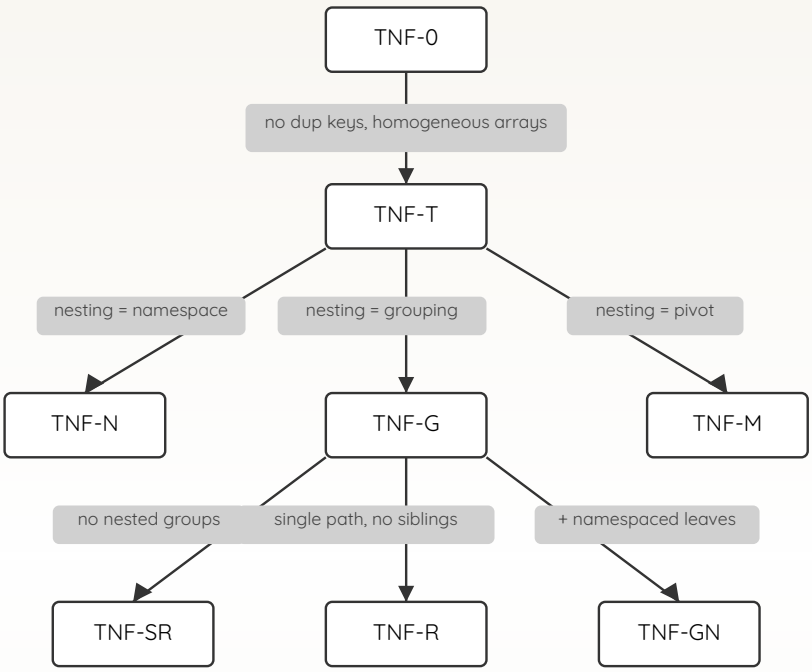


Figure 5: Mind Map

Edges represent:

Edge	Type	Meaning
TNF-0 ⟶ TNF-T	Restriction	Structural hygiene
TNF-T ⟶ TNF-N	Interpretation	Nesting means namespacing
TNF-T ⟶ TNF-G	Interpretation	Nesting means grouping
TNF-T ⟶ TNF-M	Interpretation	Nesting means pivot
TNF-G ⟶ TNF-SR	Restriction	No nested groups (flat)
TNF-G ⟶ TNF-R	Restriction	Single path, no siblings
TNF-G ⟶ TNF-GN	Combination	Grouping with namespaced leaves

Table 50: Tree normal form edge types

The graph admits extension. New forms slot in by defining their edges.

6.1. THE FORMS

6.1.1. TNF-0: Valid JSON

The baseline: any valid JSON per RFC 7159.

- Keys may be duplicated
- Arrays may be heterogeneous
- Top-level value may be a scalar
- Objects may be empty

```
42
```

```
[ 1, [], "a string", true, {},
  { "a": [2, 3], "a": [2, 3] },
  [ 2, 3, [ 4, 5 ] ]
]
```

Relational interpretation: None guaranteed. This is raw material. But it's still queryable – pathing and `json_each` work on any valid JSON.

6.1.2. TNF-T: Well-Typed JSON

Restriction from TNF-0: no duplicate keys, homogeneous arrays, non-empty objects, array or object at top level.

```
{
  "name": "Alice",
  "scores": [95, 87, 91]
}
```

Relational interpretation: Arrays can be interpreted as collections; objects as records. Pathing is unambiguous. But nesting semantics are not yet defined – is a nested object a namespace? A grouped row? A pivot?

TNF-T is the foundation for the interpretive forms that follow.

6.1.3. TNF-N: Namespaced

Interpretation from TNF-T: nesting means semantic organization.

Nested objects group related fields – structure, not data rows.

```
{
  "LastName": "eklund",
  "address": {
    "City": "boston",
    "State": "MA"
  }
}
```

The `address` object is a namespace. The tree is semantically equivalent to:

```
{
  "LastName": "eklund",
  "address_City": "boston",
  "address_State": "MA"
}
```

Relational interpretation: Namespaced trees flatten to a single row. Pathing (`.address.City`) navigates the namespace.

Trade-off: More expressive (preserves semantic grouping) but less directly relational (requires flattening).

6.1.4. TNF-G: Grouped

Interpretation from TNF-T: nesting means aggregation.

Arrays represent grouped rows – the result of `GROUP BY`.

```
[
  { "Title": "Engineer",
    "people": [
      { "FirstName": "Alice", "LastName": "Smith" },
      { "FirstName": "Bob", "LastName": "Jones" }
    ]
  },
  { "Title": "Manager",
    "people": [
      { "FirstName": "Carol", "LastName": "White" }
    ]
  }
]
```

Each nesting level is a grouping context. The outer array groups by `Title`; the inner `people` array collects rows within each title.

Relational interpretation: Direct correspondence to `GROUP BY`. Construction compresses cardinality; destructuring expands it.

6.1.5. TNF-M: Metadata-Keyed

Interpretation from TNF-T: nesting means pivot.

Data values become object keys.

```
{
  "Engineer": [
    { "FirstName": "Alice", "LastName": "Smith" }
  ],
  "Manager": [
    { "FirstName": "Carol", "LastName": "White" }
  ]
}
```

The keys (`Engineer`, `Manager`) are data values lifted to metadata.

Relational interpretation: Keys map to a column; values map to grouped rows. Destructuring recovers the key as a column value.

Trade-off: Convenient for lookup but constrained – only one column can serve as keys per level. Two metadata-keyed objects with the same key type create ambiguous destructuring.

6.1.6. TNF-SR: Simply Relational

Restriction from TNF-G: no nested groups.

A flat array of homogeneous objects – the simplest grouped form.

```
[
  { "Title": "Engineer", "FirstName": "Alice",
"LastName": "Smith" },
  { "Title": "Engineer", "FirstName": "Bob",
"LastName": "Jones" },
  { "Title": "Manager", "FirstName": "Carol",
"LastName": "White" }
]
```

No nested arrays. Each object is a row; the array is a table.

Relational interpretation: Direct. The JSON is a table in array-of-objects form. No grouping, no hierarchy – just rows.

6.1.7. TNF-R: Round-Trippable

Restriction from TNF-G: single path from root to deepest leaf, no sibling groups.

```
[
  { "Title": "Engineer",
    "State": "CA",
    "people": [
      { "FirstName": "Alice", "LastName": "Smith" }
    ]
  }
]
```

Relational interpretation: Lossless. `relation → tree → relation` recovers the original data (modulo column order).

Why siblings break round-tripping:

delightql

```
employee(*) ~> { Title,
                 "people": ~> {FirstName, LastName},
                 "cities": ~> [City] }
```

Siblings aggregate independently. The join – which person was in which city – is not preserved. Destructuring recovers each path independently:

- `Title`, `FirstName`, `LastName` (via `people`)
- `Title`, `City` (via `cities`)

But not the original four-column row. This is TNF-G but not TNF-R.

6.1.8. TNF-GN: Grouped with Namespaced Leaves

Combination of TNF-G and TNF-N: grouping structure with namespaced leaf objects.

```
[
  { "Title": "Engineer",
    "people": [
      { "name": { "first": "Alice", "last": "Smith" },
        "contact": { "email": "alice@x.com", "phone":
"555-1234" }
      }
    ]
  }
]
```

The outer structure is grouped (array of objects with nested arrays). The leaf objects use namespacing (`name`, `contact`).

Relational interpretation: Destructure the grouping levels; flatten the namespaced leaves. The result has columns `Title`, `name_first`, `name_last`, `contact_email`, `contact_phone`.

6.2. MIXING FORMS

Real trees often combine forms at different levels. The graph shows which combinations make sense:

```
{
  "metadata": {
    "generated": "2024-01-15",
    "version": "1.0"
  },
  "data": [
    { "Title": "Engineer",
      "people": [
        { "FirstName": "Alice", "LastName": "Smith" }
      ]
    }
```

```
  ]
}
```

- `metadata` is TNF-N (namespacing)
- `data` is TNF-G (grouping)

The relational interpretation:

- Flatten `metadata.generated`, `metadata.version` to columns
- Destructure `data` → `data.people` to rows
- Result: one row per person, metadata fields repeated

Understanding which form applies where clarifies what operations make sense.

6.3. EDGE TYPES

The graph has two kinds of edges:

Restriction edges add structural constraints: - TNF-0 → TNF-T: hygiene (no dup keys, homogeneous arrays) - TNF-G → TNF-SR: flatness (no nested groups) - TNF-G → TNF-R: single-path (no siblings)

Interpretation edges assign meaning to structure: - TNF-T → TNF-N: nesting is namespacing - TNF-T → TNF-G: nesting is grouping - TNF-T → TNF-M: nesting is pivot

Restriction edges constrain what trees are valid. Interpretation edges determine how to read them relationally.

6.4. SUMMARY

Form	Key Property	Relational Interpretation
TNF-0	Valid JSON	None guaranteed; queryable via pathing
TNF-T	Well-typed	Arrays are collections; objects are records
TNF-N	Namespaced	Flatten to single row
TNF-G	Grouped	GROUP BY; destructure to rows
TNF-M	Metadata-keyed	Pivot; keys become column values

Form	Key Property	Relational Interpretation
TNF-SR	Simply relational	Direct table (array of flat objects)
TNF-R	Round-trippable	Lossless construction/destruction
TNF-GN	Grouped + name-spaced	Destructure groups, flatten name-spaces

Table 51: Summary of tree normal forms

The forms answer different questions:

- **TNF-0 / TNF-T:** Is this JSON structurally sound?
- **TNF-N / TNF-G / TNF-M:** What does nesting mean here?
- **TNF-SR / TNF-R:** How constrained is the grouping?
- **TNF-GN:** Can I mix interpretations?

Tree normal forms are not prescriptive – TNF-0 is sometimes exactly what you need. They are a vocabulary for understanding what your tree structure means relationally, and what operations it supports.

6.5. EXTENDING THE GRAPH

The graph admits new forms by defining edges. Examples:

- **TNF-MR** (metadata-keyed, round-trippable): TNF-M + single-path constraint
- **TNF-SN** (simply namespaced): TNF-N + flat (no nested namespaces)
- **TNF-GM** (grouped + metadata): grouping with metadata-keyed intermediate levels

Each new form names a useful combination.

6.5.1. Guiding Principles

1. **Trees and tables mix.** Trees have a valid relational interpretation under certain structural constraints.
2. **Start with relations.** The cleanest trees arise from grouping relations, not from arbitrary JSON. Construction informs understanding.

3 **Arrays are rows; objects are records.** Arrays represent homogeneous collections (multiple rows of the same shape). Objects represent heterogeneous structure (named fields, like columns).

4 **Grouping compresses; destructuring expands.** Construction decreases cardinality (many rows → fewer rows with nested arrays). Destructuring increases cardinality (nested arrays → many rows).

5 **Siblings lose information.** Sibling tree groups aggregate independently. The relationship between siblings – which person was in which city – is not preserved. This is inherent, not a bug.

6 **Metadata-oriented trees are pivots.** When data values become object keys, the structure resembles a pivot table. This helps with the object-relational impedance mismatch but introduces constraints.

7 **Zeroth normal form has its place.** Arbitrary JSON can still be queried via `json_each` and pathing. Tree normal forms define what's cleanly relational, not what's queryable at all.

7. APPENDIX: ERROR URI TAXONOMY

Every compilation error carries a hierarchical URI that identifies the error category. Error hooks use these URIs for prefix matching:

delightql

```
-- matches any DQL semantic error
users(*) |> (foo.*) (~~error://dql/semantic ~~)

-- matches only table resolution failures
nonexistent_table(*) (~~error://dql/semantic/resolution/
table ~~)

-- matches any error at all
bad_query(*) (~~error ~~)
```

The URI is a stable identifier independent of the error message text. It doubles as the canonical reference for documentation, tooling, and diagnostics.

7.1. DESIGN PRINCIPLES

1. **Domain first.** The top level identifies the language being processed: `dql/`, `ddl/`, `dml/`. Users know whether they wrote a query or a definition.
2. **Parse vs semantic.** The second level is the classic compiler split. Parse errors mean the source text is structurally invalid. Semantic errors mean the structure is valid but the meaning is wrong.
3. **Prefix matching does the work.** Each level narrows usefully: `error://dql` catches any DQL error. `error://dql/semantic` catches any semantic error. `error://dql/semantic/resolution` catches any name binding failure.
4. **No `validation`.** The term is too vague. `semantic` says what the category is. `constraint`, `arity`, `resolution` say what went wrong.

7.2. PREFIX MATCHING

Error hooks match by prefix. An expected URI of `dql/semantic` matches any actual URI that starts with `dql/semantic/`:

Expected	Matches
`error://dql`	any DQL error (parse or semantic)
`error://dql/semantic`	any semantic error
`error://dql/semantic/resolution`	`resolution/table`, `resolution/column`, `resolution/ambiguous`, etc.
`error://dql/semantic/resolution/table`	table resolution failures only
`error://dql/parse`	any parse failure
(bare)	any error

7.3. URI HIERARCHY

7.3.1. `dql/parse/` — Structural Failures

The source text does not form a valid CST, or CST-to-AST conversion finds malformed structure. The problem is syntactic.

URI	Condition	Trigger
`dql/parse`	Any parse failure	
`dql/parse/tree_sitter`	Tree-sitter library error	
`dql/parse/literal`	Malformed literal	`0xGG`, `0o89`
`dql/parse/expression`	Malformed expression	`x +`, empty expression
`dql/parse/anon`	Malformed anonymous table	`_(a @ 2, 3)`
`dql/parse/pipe`	Malformed pipe expression	`x /->`

URI	Condition	Trigger
`dql/parse/function`	Malformed function call	missing name, lambda body
`dql/parse/case`	Malformed CASE expression	missing arm, missing result
`dql/parse/window`	Malformed window spec	invalid frame mode
`dql/parse/json_path`	Malformed JSON path	`[name]`, `{42}`
`dql/parse/projection`	Empty or invalid projection	`|> -(*)`
`dql/parse/subquery`	Malformed scalar subquery	missing table, missing continuation
`dql/parse/pattern`	Malformed pattern literal	invalid `/pattern/` format

Fine-grained leaves (e.g. `dql/parse/literal/hex`) can be added later. The second level is the useful grain for error hooks.

7.3.2. `dql/semantic/` — Semantic Failures

The structure is valid but the meaning is wrong. Names do not resolve, arities do not match, or domain constraints are violated.

7.3.2.1. `dql/semantic/resolution/` — Name Binding Failures

URI	Condition	Trigger
`dql/semantic/resolution`	Any name binding failure	
`dql/semantic/resolution/table`	Table or view not found	`nonexistent(*)`
`dql/semantic/resolution/column`	Column cannot be resolved	`|> (bad_col)`
`dql/semantic/resolution/function`	Function or HO view not found	
`dql/semantic/`	Sigma predicate not found	

URI	Condition	Trigger
`resolution/sigma`		
`dql/semantic/resolution/ambiguous`	Name matches multiple entities	cross-join with shared column
`dql/semantic/resolution/scope`	Name exists but unreachable	column behind pipe barrier, post-group leak

Why `ambiguous` lives under `resolution`. Ambiguity is the dual of not-found: resolution fails because there are zero matches (not found) or multiple matches (ambiguous). Both are failures of name binding.

Why `scope` lives under `resolution`. The name exists in the schema, but the current scope cannot see it. The column is behind a pipe barrier, or a group-by reduced the visible columns. It is a resolution failure with a specific cause.

7.3.2.2. `dql/semantic/arity/` — Wrong Argument Count

URI	Condition	Trigger
`dql/semantic/arity`	Wrong argument count (general)	
`dql/semantic/arity/function`	Function call arity	
`dql/semantic/arity/predicate`	Predicate arity	`+between(1, age)`
`dql/semantic/arity/sigma`	Sigma predicate arity	
`dql/semantic/arity/pattern`	Positional pattern element count	`users(a, b, c)`

Why `arity` is separate from `resolution`. Resolution is about finding the entity. Arity is about calling it. A function can resolve successfully and still fail on arity. These are

different failure modes with different fixes: “did you spell it right?” vs “did you pass the right number of arguments?”

7.3.2.3. `dql/semantic/constraint/` — Domain Rule Violations

The query is valid and all names resolve with correct arity, but a domain-specific rule is violated.

URI	Condition	Trigger
`dql/semantic/constraint`	Any constraint violation	
`dql/semantic/constraint/pivot`	Pivot requirements not met	missing IN predicate, duplicate column
`dql/semantic/constraint/destructuring`	Destructuring rule violated	multiple ~>, comparison in pattern
`dql/semantic/constraint/join`	Join constraint violated	multiple full outer, missing condition
`dql/semantic/constraint/context`	Context-aware function misuse	typo, wrong args, missing marker
`dql/semantic/constraint/unsupported`	Construct not supported in this position	IN in projection, EXISTS in CASE

Why `constraint` replaces `validation`. The word `constraint` names what went wrong: a domain rule was violated. Pivot requires an IN predicate. Destructuring forbids comparisons. Full outer join cannot have multiple targets. These are specific rules, not generic “validation.”

7.3.2.4. `dql/semantic/limitation/` — Known Limitations

URI	Condition
`dql/semantic/limitation`	Any known limitation
`dql/semantic/limitation/qualified_name_ambiguity`	Grammar ambiguity with qualified names ending in `!`.

URI	Condition
`dql/semantic/limitation/not_implemented`	Feature not yet implemented

7.3.3. `ddl/` — DDL Errors

DDL errors are structurally similar to DQL errors but fewer in number.

URI	Condition
`ddl/parse`	DDL syntax failure
`ddl/semantic/resolution`	Referenced entity not found
`ddl/semantic/constraint`	DDL rule violated (circular dependency, duplicate definition)

7.3.4. `dml/` — DML Errors

URI	Condition
`dml/parse`	DML syntax failure
`dml/semantic/resolution`	Target entity not found
`dml/semantic/constraint`	DML rule violated

7.3.5. `database/` and `io/` — Runtime Errors

These errors occur during query execution, not compilation. They do not belong to a language domain.

URI	Condition
`database`	Any database operation error
`database/connection`	Connection lock poisoned
`io`	I/O error

7.4. IMPLEMENTATION NOTES

The current implementation derives subcategories from error message keywords for `ValidationError`, `TransformationError`, and `TranspilationError`. Stable, sta-

tic error types (`TableNotFoundError`, `ColumnNotFoundError`) already carry precise URIs. A planned refactor will add explicit subcategory fields to all dynamic error types, making URIs independent of message text.

8. APPENDIX: DANGER URI TAXONOMY

Certain behaviors are safe in most contexts but dangerous in others. Rather than forbid them outright, delightql gates them behind danger URIs – named safety boundaries that are closed by default and opened explicitly per-query.

delightql

```
-- open a specific danger for one query
employee(*) as e (~~danger://dql/cardinality/nulljoin
ON~~),
  department(*) as d,
  e.DepartmentId = d.DepartmentId

-- the danger auto-closes at query end
employee(*) as e, department(*) as d,
  e.DepartmentId = d.DepartmentId
-- this query uses safe defaults again
```

The URI is a stable identifier. It doubles as the canonical reference for documentation, tooling, and diagnostics – the same role that error URIs serve for compilation errors.

8.1. DESIGN PRINCIPLES

1. **Off by default.** Every danger starts OFF. The safe behavior is active unless the programmer explicitly requests otherwise.
2. **Domain first.** The top level identifies the language domain: `dql/`, `ddl/`, `dml/`. This mirrors the error URI hierarchy.
3. **What-goes-wrong second.** The second level names the category of harm: `cardinality/` (row-count blowup), `termination/` (non-halting computation), `precision/` (silent data loss). Where error URIs use what phase failed (parse, semantic), danger URIs use what goes wrong – because dangers are not phase-specific.
4. **Prefix matching does the work.** Each level narrows usefully. `danger://dql` catches any DQL danger. `danger://dql/cardinality` catches any cardinality blowup. `danger://dql/cardinality/nulljoin` catches only that specific case.

5 **No bare form.** `(~~danger://dql/cardinality/nulljoin~~)` without `ON` or `OFF` is an error. Being explicit about the toggle is the entire point.

6 **Query-scoped.** A danger gate opens for one query and auto-closes at query end. It does not leak into subsequent queries.

7 **The URI is the documentation.** The danger URI in source code is also the canonical reference for what the danger means and why it exists.

8.2. SYNTAX

```delightql
employee(*) as e (~~danger://dql/cardinality/nulljoin
ON~~),
  department(*) as d,
  e.DepartmentId = d.DepartmentId
```

The annotation lives inside the annotation delimiters (`~~ ... ~~`) and attaches at a continuation point (after a relation). It is an annotation that travels with the query but is not part of the relational algebra.

Component	Meaning
`danger://`	URI scheme identifying a danger gate
`dql/cardinality/nulljoin`	Hierarchical path to the specific danger
`ON`	Enable the dangerous behavior for this query
`OFF`	Restore the safe default (useful to override a CLI baseline)
`ALLOW`	Permit but do not force – the compiler may use the dangerous path if needed
`1-9`	Graduated severity levels for host-defined behavior

8.2.1. Toggle Values

`ON` and `OFF` are the common cases. They are binary: the dangerous behavior is either active or not.

`ALLOW` is a middle ground. It tells the compiler that the dangerous behavior is acceptable but not required. The compiler may choose the safe path when it can and the dangerous path when it must. This is useful for queries where the programmer has verified that the data does not trigger the danger but wants the compiler to retain latitude.

The severity levels `1` through `9` exist for host-defined policies where binary on/off is too coarse. The language defines no semantics for specific levels – the host interprets them. Example uses:

- A linter that warns at level 3 but errors at level 7
- A monitoring system that logs at level 1 but alerts at level 5
- A deployment pipeline that permits level 1-4 in staging but only level 1-2 in production

The severity levels are ordered: higher numbers indicate greater willingness to accept the danger. A tool checking "is danger level at least N?" can compare numerically.

Multiple dangers may be opened for the same query:

delightql

```
employee(*) as e
  (~~danger://dql/cardinality/nulljoin ON~~)
  (~~danger://dql/cardinality/cartesian ON~~),
  department(*) as d,
  e.DepartmentId = d.DepartmentId
```

8.3. DEFAULTS AND OVERRIDES

The program starts with a default table where every danger is OFF:

```
danger://dql/cardinality/nulljoin            OFF
danger://dql/cardinality/cartesian           OFF
danger://dql/termination/unbounded           OFF
danger://dql/semantics/min_multiplicity      OFF
```

8.3.1. Override Scopes

Not all dangers accept overrides from the same places. The scope at which a danger can be overridden depends on whether it changes language semantics or execution guardrails:

URI	Inline	File	CLI	Category
`dql/cardinality/nulljoin`	yes	yes	**no**	semantic
`dql/cardinality/cartesian`	yes	yes	yes	guardrail
`dql/termination/unbounded`	yes	yes	yes	guardrail
`dql/semantics/min_multiplicity`	yes	yes	**no**	semantic

Semantic dangers change what operators mean. The `nulljoin` gate redefines = in join position from SQL = to `IS NOT DISTINCT FROM`. A DQL script should mean the same thing regardless of who runs it and what CLI flags they pass. Semantic overrides must live in the source text – either inline on the query or at the top of the file – so the script is self-documenting.

Guardrail dangers control whether the engine permits certain operations. They do not change expression semantics. Cartesian product rejection and unbounded recursion prevention are resource limits, not language redefinitions. These may be overridden at any scope, including the CLI.

The guiding principle: **operator semantics are fixed by the source text.** CLI flags may change SQL shape (via `option://`) or execution policy (via guardrail `danger://`), but never language meaning.

8.3.2. Session Baseline (CLI)

The CLI can shift the baseline for guardrail dangers:

```
dql query --danger dql/cardinality/cartesian=ON --db
test.db "..."
```

Attempting to override a semantic danger from the CLI is an error:

```
# REJECTED: nulljoin is a semantic danger -- use inline
annotation
dql query --danger dql/cardinality/nulljoin=ON --db
test.db "..."
```

8.3.3. Override Precedence

Per-query annotations override the file-level directive. The file-level directive overrides the session baseline. At query

end, the danger reverts to the file-level or session-level value:

```
CLI baseline  ---->  file directive  ---->  per-query
---->  revert
    OFF                   ON                   OFF
ON
```

8.4. PREFIX MATCHING

Danger hooks match by prefix, identically to error hooks:

Expected	Matches
`danger://dql`	any DQL danger
`danger://dql/cardinality`	`nulljoin`, `cartesian`, any future cardinality danger
`danger://dql/cardinality/nulljoin`	null-join only
`danger://dql/termination`	`unbounded`, any future termination danger

8.5. URI HIERARCHY

8.5.1. `dql/cardinality/` — Row-Count Blowups

The query may produce far more rows than the programmer expects. These dangers guard against silent multiplicative explosions in result cardinality.

URI	Default	Condition	What happens when ON
`dql/cardinality/nulljoin`	OFF	`=` in join position compiles to SQL `=`	`=` in join position compiles to `IS NOT DISTINCT FROM`. NULL keys match each other, producing a cartesian product of all NULL rows.
`dql/cardinality/cartesian`	OFF	Cross joins without an explicit condition are rejected	Cross joins without conditions are permitted.

Why `nulljoin` is a cardinality danger. The NULL-by-NULL cross product is a multiplicative blowup. Five NULLs on the left and three on the right produce fifteen matched rows. The danger is not that NULLs participate in the join – it is that they participate combinatorially.

Why `cartesian` is a cardinality danger. A cross join of two million-row tables produces a trillion rows. Explicit cross joins are sometimes intended (for generating combinations), but an accidental cross join – one caused by a missing join condition – is one of the most common and costly SQL mistakes.

8.5.2. `dql/termination/` — Non-Halting Computation

The query may not terminate.

URI	Default	Condition	What happens when ON
`dql/termination/unbounded`	OFF	Recursive CTEs must include a termination condition	Recursive CTEs without termination conditions are permitted.

Why `unbounded` is a termination danger. A recursive CTE without a termination condition produces an infinite result. In practice, the database engine will hit a resource limit and error – but only after consuming significant time and memory. The compiler can detect the absence of a termination condition statically and reject it early.

8.5.3. `dql/semantics/` — Operator Semantics

The query's meaning changes. These dangers alter what an operator computes, not merely whether it is permitted. They are semantic dangers: inline-only, never CLI-overridable.

URI	Default	Condition	What happens when ON
`dql/semantics/min_multiplicity`	OFF	Intersection-via-correlation uses bidirectional semijoin (UNION ALL of	Intersection-via-correlation uses ROW_NUMBER + equijoin, producing min(m,n) copies – true INTERSECT ALL multiplicity.

URI	Default	Condition	What happens when ON
		EXISTS-filtered operands), producing m+n copies of matching tuples	

Why `min_multiplicity` is a semantic danger. The bidirectional semijoin and the ROW_NUMBER path compute different multisets for duplicate tuples. Three copies in the left operand and two in the right yield five rows under bidirectional semijoin but two under min-multiplicity. The difference only surfaces with genuinely duplicate tuples, but it changes what the operator means – the same query produces different results. This is a semantic redefinition, so it must live in the source text.

8.5.4. Future Categories

The hierarchy is designed to grow. Possible future categories:

8.5.4.1. `dql/precision/` — Silent Data Loss

URI	Condition
`dql/precision/implicit_cast`	Implicit type coercion that loses information
`dql/precision/truncation`	String or numeric truncation without warning

8.5.4.2. `dml/destructive/` — Irreversible Mutations

URI	Condition
`dml/destructive/unfiltered_update`	UPDATE without a WHERE condition
`dml/destructive/unfiltered_delete`	DELETE without a WHERE condition

8.6. RELATIONSHIP TO ERROR URIS

Danger URIs and error URIs are sibling systems:

	Error URIs	Danger URIs
Scheme	`error://`	`danger://`
When	After compilation fails	Before compilation (gate check)
Mechanism	Prefix matching for error hooks	Prefix matching for gate control
Top level	Domain (`dql/`, `ddl/`, `dml/`)	Domain (`dql/`, `ddl/`, `dml/`)
Second level	Phase (`parse/`, `semantic/`)	What goes wrong (`cardinality/`, `termination/`)
Default	Errors always fire	Dangers always off

Both use hierarchical URIs. Both support prefix matching. Both serve as stable identifiers for documentation and tooling. The difference is directional: error URIs report what went wrong; danger URIs prevent what could go wrong.

9. NAMESPACE DIRECTIVES

9.1. THE IMAGE

A DQL session is a filesystem. You mount databases, install libraries, create directories. When you close the lid, the state persists. When you reopen it, everything is where you left it.

```
~::                              -- your home directory
├── data::wh                     -- a mounted database
├── analytics                    -- a consulted DDL
library
│   └── helpers                  -- the library's
internal dependency
├── analytics::grounded          -- library bound to
data
└── scratch                      -- a namespace you made
```

`~::` is home. `::` is root (where `sys` and `std` live). Directives are the shell commands that shape this tree. Queries run inside it.

The image is a SQLite file – the bootstrap database serialized to disk. Not a replay script, but the actual state: namespace tree, entity definitions, connection metadata, timestamps, history. Since DQL already uses SQLite for its internal state, the image format is the system's own storage format. Dogfooding.

```
# Ephemeral (default) -- fresh home, dies on exit
echo 'users(*)' | dql query --db warehouse.db

# Persistent -- your laptop
dql --session workspace.db --db warehouse.db -i
> mount!("ref.db", "data::ref")
> consult!("analytics.dql", "analytics")
> weekly_report(*)
> .quit                          # state saved to
workspace.db

# Next day -- everything is where you left it
dql --session workspace.db -i
> weekly_report(*)               # just works
```

The image is queryable. `mount!("old_session.db", "prev")` and browse what you had last week. Diff two environments by joining their bootstrap tables. The session IS a database.

This is the Smalltalk image model applied to a query environment. Smalltalk's images were opaque heap dumps. Jupyter notebooks improved this with ordered cells, but introduced a desync problem – run cells out of order and the kernel diverges from what the notebook shows. A DQL image has neither problem: it's inspectable (it's SQLite) and it's the actual state (not a recipe that might diverge).

9.2. DIRECTIVES

Queries transpile to SQL. Directives shape the environment in which queries run. `mount!` doesn't produce SQL – it connects a database. `consult!` loads view definitions. `enlist!` makes names visible.

Every directive produces, consumes, borrows, or transforms a namespace.

9.2.1. Produce

```
mount!("warehouse.db", "data::wh")        -- connect
database → DataNs
consult!("analytics.dql", "analytics")     -- load DDL
file → LibNs
copy!("subset")                            -- pipe
terminal: create from entity metadata → LibNs
consult_tree!("models/", "lib")            -- directory
tree → nested LibNs
mount_tree!("postgres://host/db", "data")  -- database
catalog → nested DataNs
```

The `_tree` variants mirror an external hierarchy (filesystem or database catalog) into the namespace tree. The caller names the root; the source names the branches. `models/util/greet.dql` becomes `lib::util::greet`.

9.2.2. Consume

```
unmount!("data::wh")
unconsult!("analytics")
```

```
imprint!("analytics", "data::wh")          --
materializes views as tables, consumes LibNs
```

`imprint!` is linear – the library namespace is consumed. This prevents ghost duality (abstract definitions alongside concrete tables that inevitably drift).

9.2.3. Borrow

```
ground!("data::wh", "analytics", "analytics::g")    --
bind lib to data → GroundedNs
serialize!("analytics", "backup.dql")                --
write to file
```

9.2.4. Transform

```
refresh!("data::wh")            -- re-introspect schema
reconsult!("analytics")         -- reload from file
```

9.2.5. Scope-local (visibility)

```
enlist!("analytics")            -- bare names visible in
my scope
alias!("data::wh", "wh")       -- wh.users(*) shorthand
delist!("analytics")            -- remove enlistment +
alias
```

Scope-local operations are saved/restored at DDL boundaries. A DDL that enlists a namespace doesn't pollute its caller.

9.2.6. Scratch namespaces

Inline DDL (`(~~ddl:"name" ~~)`) creates scratch namespaces that are **ambient** – they automatically bind to the database they were created under. A consulted library needs explicit `ground!` to connect its table references to data. A scratch namespace doesn't – you're defining views against the database that's right here, and the system captures that binding at creation time.

```
(~~ddl:"helpers"
  young(*) :- users(*), age < 20
~~)
enlist!("helpers")
young(*)         -- users resolves against the current
database
```

See `book/design/inline-ddl.md` for details on ambient binding, provenance, and the relationship between scratch and consulted namespaces.

9.2.7. Execution

```
play!("setup.dql")                    -- execute in my
scope (source)
exec!("report.dql") |> (total)        -- execute, return
last expression
run!("job.dql", "sandbox")            -- isolated sub-
session
save!()                               -- persist ~:: to
session file
```

9.3. PIPE SCHEMAS

Every directive produces one unnamed positional column: the namespace it affected. No status column – rows mean success, errors mean failure.

```
consult!("a.dql","ns1";"b.dql","ns2")(*) |> enlist!()
lib::(*) |> pick("view1";"view2") |> copy!("subset")
mount!("a.db","da";"b.db","db")(*) |> enlist!()
```

Scalar-lifted arguments (`;` between pairs) produce multiple rows. Pipe terminals read the single column positionally.

9.4. NESTING

DDL files don't know their own name. The caller chooses:

```
consult!("analytics.dql", "analytics")   -- caller's
choice
consult!("analytics.dql", "reports")     -- different
caller, different name
```

A DDL that needs helpers cannot self-nest – it doesn't have `crate::` or `__name__`. Auto-nesting solves this: directives inside a DDL are prefixed under the DDL's namespace automatically.

```
-- Inside analytics.dql:
consult!("helpers.dql", "helpers")     -- becomes
analytics::helpers
```

```
consult!("shared.dql", "::shared")    -- :: escapes to
global root
```

Prefix	Target	Unix analogy
(bare)	relative to current DDL	./
~::	session root	~/
::	global root	/

When two DDLs consult the same file, the namespace tree has two entries. The engine shares resources behind the scenes (connections are ref-counted by URI). The semantics are value-level copies; the implementation shares structure. Functional data structures.

9.5. OWNERSHIP

Namespace directives have ownership semantics. Each directive either produces, consumes, borrows, or transforms a namespace resource.

Key rules: - Can't `unmount!` a DataNs that's borrowed by a `ground!` - Can't `unconsult!` a LibNs that's borrowed by a `ground!` - `imprint!` consumes the LibNs – use-after-imprint is an error - `delist!` drops both enlistments and aliases - Destroying a parent namespace cascades to children

These enforce real invariants (no dangling views, no stale groundings) through the type system rather than programmer discipline.

Full directive signatures with ownership annotations are in `DESIGN-namespace-directives.md`.

9.5 BIBLIOGRAPHY

Darwen, Hugh. “HAVING A Blunderful Time.” Accessed December 26, 2024. https://www.dcs.warwick.ac.uk/~hugh/TTM/HAVING-A-Blunderful-Time.html.

s.n. Join (SQL) – Wikipedia. “Join (SQL) — Wikipedia, the Free Encyclopedia.” 2024. https://en.wikipedia.org/w/index.php?title=Join_(SQL)&oldid=1237592281#Full_outer_join.

9.5 FIGURES