

SQL99, SQL/MM, and SQLJ: An Overview of the SQL Standards

Nelson M. Mattos

with contributions from Kathryn Zeidenstein, Krishna Kulkarni, Stefan Dessoach, Hugh Darwen, Paul Cotton, Peter Pistor, Curt Cotner, Bob Lyle, Bill Bireley, and many others

IBM Database Common Technology



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SQL Foundation *continued*

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▼ Disclaimers

- The content of this presentation is not intended to represent the viewpoint of IBM, NCITS, or ISO DBL.
- This presentation does not cover all features of SQL99, SQL/MM, and SQLJ.
 - Not all options are presented
 - Examples do not include error handling, and may contain simplifications and /or inaccuracies
- Any problems caused by mistakes in this presentation are solely the responsibility of the user.

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▼ SQL Standard

- Goal: enable the portability of SQL applications across conforming products
- Side effect: Increases and stabilizes the database market
- Joint efforts between vendors and users
 - Computer Associates
 - IBM
 - Informix
 - Oracle
 - Sybase
 - Microsoft
 - etc.
- Joint effort among several countries

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Database Standards Organizations: JTC1

- JTC1/SC32: Data Management and Interchange
 - ▶ WG1: Open EDI (Finland)
 - ▶ WG2: Metadata (USA)
 - ▶ WG3: Database Languages (Netherlands)
 - ▶ WG4: SQL Multimedia and Application Packages (Japan)
 - ▶ WG5: Remote Database Access (RDA) (United Kingdom)
 - ▶ RG1: Reference Model for Data Management (Maintenance) (United Kingdom)
 - ▶ RG2: Export /Import (Maintenance) (Canada)

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Database Standards Organizations: JTC1

- JTC1/SC32/WG3 Projects (SQL3 only):
 - ▶ Part 1: Framework
 - ▶ Part 2: Foundation
 - ▶ Part 3: Call-Level Interface
 - ▶ Part 4: Persistent Stored Modules
 - ▶ Part 5: Language Bindings
 - ▶ Part 6: XA Specialization
 - ▶ Part 7: Temporal
 - ▶ Part 9: Management of External Data
 - ▶ Part 10: Object Language Bindings
- JTC1/SC32/WG4 Projects:
 - ▶ Part 1: SQL/MM Framework
 - ▶ Part 2: SQL/MM Full-Text
 - ▶ Part 3: SQL/MM Spatial
 - ▶ Part 4: SQL/MM General Purpose Facilities
 - ▶ Part 5: SQL/MM Still Image

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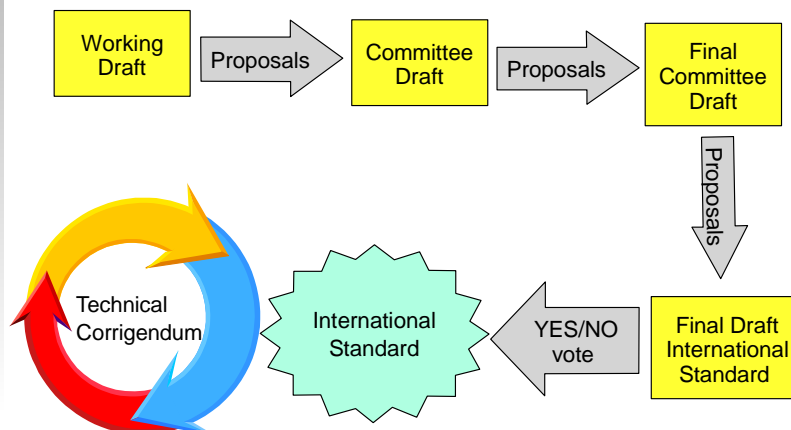
Database SQL Standards

- Specification:
 - Vendor extensions allowed
 - Implementation-defined behaviors exist
- Players
 - US: **ANSI NCITS H2** Database Language Committee
 - Mix of vendors (18) and users (13)
 - International: **ISO/JTC1 SC32/WG3 DBL** Working Group (Database Languages)
 - 11 countries participating
- **JTC1**
 - **SC32**
 - **WG3** (Database languages)
 - **WG4** (SQL/MM)
 - ...
 - **TC211** (Geographic information/Geomatics)
- **ANSI (USA)**
 - **NCITS**
 - **H2**
 - **H2.2** (CLI)
 - ...
 - ...
- **DIN (Germany)**
 - **NI**
 - **NI 32**
 - ...
 - **NABau**
 - **Arbeits-Ausschuss Kartographie und Geoinformation**
- Consortia: **SQLJ**
 - Major database vendors

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Database SQL Standard

- Process
 - Standards are produced by volunteers
 - Open process oriented towards achieving consensus
 - Proposals to change existing base document
- Life cycle of an ISO standard:



- Review every 5 years to reaffirm, replace, or withdraw

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Other Related Standards

- **NDL: (X3.133-1986)**
 - ▶ Network Database Language
 - ▶ Has been reaffirmed for another 5 years
 - ▶ Cancelled as international standard

- **RDA: (IS 9579-1: 1993, IS 9579-2:1993)**
 - ▶ Remote Database Access
 - ▶ Defines client/server protocol
 - ▶ IS 9579-1: Information Technology - Remote Database Access - Part 1: Generic Model, Service, and Protocol
 - ▶ IS 9579-2, Information Technology - Remote Database Access - Part 2: SQL Specialization
 - ▶ RDA/SQL Amendm.1: Secure RDA (work in progress)
 - ▶ RDA/SQL Amendm.2: Distribution Schema for RDA (work in progress)
 - ▶ RDA/SQL Amendm.3: Encompassing Transaction (work in progress)
 - ▶ RDA/SQL Support for SQL3 (work in progress)

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DBL Project History

early 70's	Ted Codd's first papers on Relational Algebra
1975	CODASYL Database Specifications
1977	database Project Initiated in U.S.
1978	ANSI Database Project Approved
1979	ISO Database Project Initiated
1982	ANSI Project Split into NDL and SQL
1983	ISO Project Split into NDL and SQL
1986	ANSI SQL Published - December
1987	ISO/IEC 9075:1986 (SQL86)
1989	ISO/IEC 9075:1989 (SQL89)
1992	ISO/IEC 9075:1992 (SQL92)
1995	ISO/IEC 9075-3:1995 (SQL/CLI for SQL92)
1996	ISO/IEC 9075-4:1996 (SQL/PSM for SQL92)

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▼ Progression of SQL Standards

- SQL/86
- SQL/89 (FIPS 127-1)
- SQL/89 with Integrity Enhancement 120pp
- SQL/92 622pp July 92
 - Entry Level (FIPS 127-2)
 - Intermediate Level
 - Full Level
- SQL CLI 200pp Sept 95
- SQL PSM 250pp Nov 96
- SQL/3 (Work in Progress)
 - SQL Framework 20pp May 99
 - SQL Foundation 900pp May 99
 - SQL Call Level Interface (CLI) 100pp Dec 99
 - SQL Persistent Stored Modules (PSM) 150pp May 99
 - SQL Language Bindings 200pp May 99
 - SQL Management of External Data 112pp Jul 00
 - SQL Object Language Bindings 238pp Feb 00
- SQL/4 (Work to be defined soon)
 - All of the above, and...
 - XA
 - SQL Temporal

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▼ Progression of SQL Standards (cont.)

- SQL/MM (for SQL3)
 - Framework 007pp Oct 99
 - Full Text 208pp May 99
 - Spatial 343pp May 99
 - Still Image 045pp Oct 00
- SQL/MM "Later progression"
 - Full Text Sep 01
 - Spatial Sep 01

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▼ SQL Conforming Products

- Validation
 - Performed formerly by NIST. Discontinued in 1996. Other organizations are considering using the NIST test suite for certification.
- SQL/89
 - 11 validated products on 52 different platforms
- SQL/92
 - over 10 validated products on over 100 different platforms
 - IBM DB2
 - Informix Online
 - Microsoft SQL Server
 - Oracle 7 and Rdb
 - Software AG ADABAS D
 - Sybase SQL Server
 - etc.

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▼ SQL/86 (X3. 135-1983, ISO/IEC 9075:1986)

- The starting point: IBM's SQL implementation
 - SQL/86 became a subset of IBM's SQL implementation
- Criticized for lack of common features and orthogonality (described in next slide)
- Defined 3 ways to process DML
 - "Direct processing"
 - "Module language"
 - Embedded SQL
- Bindings to
 - Cobol
 - Fortan
 - Pascal
 - PL/1

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▼ Orthogonality: What does that mean?

"Orthogonality means *independence*.
A language is orthogonal if independent concepts are kept independent and not mixed together in confusing ways."

"..desirable because the less orthogonal a language is, the more complicated it is...and the less powerful it is."

*From A Guide to the SQL Standard,
4th Edition, by
Chris Date with Hugh Darwen*

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▼ SQL/89 (X3.135-1989, ISO/IEC 9075:1989)

- Superset of SQL/86
- Replaced SQL/86
- C and ADA were added to existing language bindings
- DDL in a separate "schema definition language"
CREATE TABLE
CREATE VIEW
GRANT PRIVILEGES
(No DROP, ALTER, OR REVOKE)

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SQL/89 with Integrity Enhancement

- DEFAULT
 - Default value for a column when omitted at INSERT time
- UNIQUE (column-list)
- NOT NULL
- Views WITH CHECK OPTION
 - Insertions to view are rejected if they don't satisfy the view-definition
- PRIMARY KEYS
- CHECK constraint
 - Integrity constraint on values in a single row
- Referential Integrity
 - CREATE TABLE T2
 - FOREIGN KEY (COL3) REFERENCES T1 (COL2)
 - Any update that would violate referential integrity is rejected

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SQL/89 Language Bindings

- Database Language Embedded SQL (X3.168-1989)
 - ANSI only, not needed in ISO
 - Necessary because embedding was defined in an appendix in SQL/86 and SQL/89
 - C and ADA language bindings (in addition to COBOL, Fortran, Pascal, and PL/I)

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SQL/92: Overview

- Superset of SQL/89
 - Very few incompatibilities documented in an annex
- Not "least-common-denominator"
- Significantly larger than SQL/89 (579 versus 120 pages)
 - Greater orthogonality
 - Data type extensions (varchar, bit, character sets, date, time & interval)
 - Multiple join operators
 - Catalogs
 - "Domains"
 - Derived tables in FROM clause
 - Assertions
 - Temporary tables
 - Referential actions
 - Schema manipulation language
 - Dynamic SQL
 - Scrollable cursors
 - Connections
 - Information schema tables

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SQL/92: Overview (cont.)

- Many (but not all) features are available in existing products
- Divided into 3 levels:
 - Entry level (much the same as SQL/89 with Integrity Enhancement)
 - Intermediate level
 - Full level
- Features are assigned to level
 - Full is a superset of Intermediate
 - Intermediate is superset of Entry
- FIPS 127-2 defines a Transitional Level:
 - Level between Entry and Intermediate
 - Subset of Intermediate
 - Superset of Entry

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SQL/92 Entry Level

- SQL/89 plus a small set of new features:
 - SQLSTATE
 - Carries more feedback information than SQLCODE
 - Delimited identifiers
`CREATE TABLE "SELECT"...`
 - Named expressions in SELECT - list:

```
SELECT name, sal+comm AS pay
FROM employee
ORDER BY pay
```

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SQL/92: Transitional Level

- Defined by FIPS 127-2
- Subset of SQL/92: Intermediate Level
- Data types and operators
`DATE, TIME, TIMESTAMP, INTERVAL (with arithmetic)`
`CHAR VARYING(n)`
`LENGTH, SUBSTR, TRIM`, and `||` (concatenate) operators
- Referential integrity with cascading delete
- New types of join
 - `NATURAL JOIN`
 - `LEFT` and `RIGHT OUTER JOIN`
- Dynamic SQL
`PREPARE`
`EXECUTE`
`DESCRIBE`

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▼ SQL/92: Transitional Level (cont.)

- Schema evolution
 - ALTER TABLE
 - DROP TABLE
 - REVOKE PRIVILEGE
- CAST (expression AS type)
 - Conversions among
 - Numeric types
 - Numeric <-> Character
 - Character <-> Date and time
- Standard Catalogs
 - TABLES VIEWS COLUMNS
 - PRIVILEGE
- Views containing UNION
- Multiple schemas (collection of tables and other objects) per user
- Transaction isolation levels
 - READ UNCOMMITTED
 - READ COMMITTED
 - REPEATABLE READ
 - SERIALIZABLE

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▼ SQL/92: Intermediate Level

- Scrollable cursors
- FULL OUTER JOIN
- Domains
 - "Macro" facility for data type, default, value, nullability, and CHECK constraint
 - No strong typing (type checking based on underlying data type)
 - Not the same as Codd's notion of domains
- Online DDL
- Implicit casting
 - Scalar-valued subquery can be used in place of any scalar

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▼ SQL/92: Intermediate Level (cont.)

- Set operations between query blocks:
 - ▶ INTERSECT
 - ▶ EXCEPT
 - ▶ CORRESPONDING (allows operators to apply to like-named columns of tables)
- CASE expression

```
SELECT CASE (sex)
WHEN "F" THEN "female"
WHEN "M" THEN "male"
END
...
```
- COALESCE
 - ▶ Returns the first non-null value
 - COALESCE (EMP.AGE, "Age is null")

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▼ SQL/92: Intermediate Level (cont.)

- UNIQUE predicate

```
UNIQUE <subquery>
```

 - ▶ Returns true if the subquery returns no duplicates; otherwise, false
- 128-character identifiers
- Multiple character sets (including double-byte)
- SET statement to change authorization-ID
- More comprehensive catalog information
 - ▶ Constraints
 - ▶ Usage
 - ▶ Domains
 - ▶ Assertions
- Date and time arithmetic with time zones
- SQL FLAGGER
 - ▶ Extensions
 - ▶ Conforming language being processed in a non-conforming way

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▼ SQL/92: Full Level

- Derived tables
 - table-expressions in FROM-clause
- Referential integrity with CASCADE UPDATE and SET NULL
- Integrity assertions
 - Stand-alone assertions that apply to entire tables or multiple tables
 - Subqueries in CHECK clause
 - Deferred checking of constraints (including assertions)
- Enhanced predicates
 - Multiple-column matching:
`WHERE (X,Y) MATCH (SELECT A, B FROM T2)`
 - Comparison by high-order and low-order columns:
`WHERE (X, Y) > (A,B)`

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▼ SQL/92: Full Level (cont.)

- More types of join
 - CROSS JOIN
 - UNION JOIN
- New data types
 - BIT (n)
 - BIT VARYING (n)
- Temporary tables (vanish at end of transaction or session)
- Implementation-defined collating sequences
- More character-string operators:
 - UPPER
 - LOWER
 - POSITION
- INSERT privilege on individual columns

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▼ SQL/92: Full Level (cont.)

- Row and table constructors:
((1, 'OPERATOR', 'JONES'),
 (2, 'PROGRAMMER', 'SMITH'),
 (3, 'MGR', 'MATTOS')
)
- Explicit Tables
 - TABLE EMP can be a subquery
- DISTINCT applies to expression:
SELECT COUNT (DISTINCT SAL+COMM)
- Cursors declared SENSITIVE (see updates after OPEN) or INSENSITIVE
- Updates via scrollable or ordered cursors
- UPDATE and DELETE with subqueries on the same table

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▼ FIPS SQL

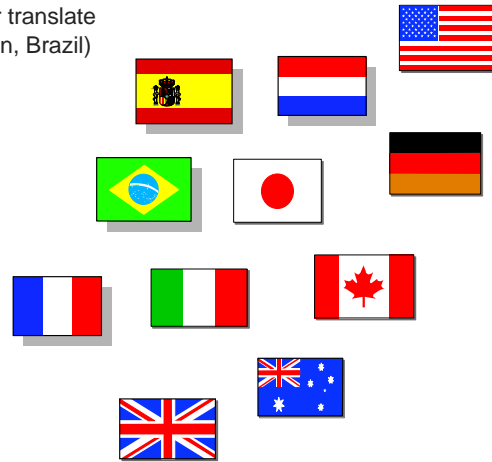
- NIST (National Institute of Standards and Technology)
 - Publishes FIPS (Federal Information Processing Standards)
- A FIPS provides guidelines for purchases by U.S. federal agencies:
 - FIPS 127 for SQL/86
 - FIPS 127-1 for SQL/89
 - FIPS 127-2 for SQL/92
- FIPS requires a FIPS flagger to detect extensions to the standard
- NIST develops test suites
 - FIPS 127-1 : close to 200 test cases
 - FIPS 127-2 for Entry Level of SQL/92: over 400 test cases
 - Performing validation tests
 - Conforming implementation placed on Validated Products List
 - Certificates of conformance issued

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SQL99 Overview

- Existing Standard
 - Development began before publication of SQL/92
 - Published in 1999
 - Identical ANSI and ISO standards
 - Other countries republish or translate the ISO standard (e.g. Japan, Brazil)

- Many contributions from ...
 - Australia
 - Brazil
 - France
 - Canada
 - Germany
 - Italy
 - Japan
 - Netherlands
 - Spain
 - UK
 - USA
 - ...



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SQL99 Overview

- Superset of SQL/92
 - Completely upward compatible
- Significantly larger than SQL/92
 - Object-Relational extensions
 - User-defined data types
 - Reference types
 - Collection types (e.g., arrays)
 - Large object support (LOBs)
 - Table hierarchies
 - Triggers
 - Stored procedures and user-defined functions
 - Recursive queries
 - OLAP extensions (CUBE and ROLLUP)
 - SQL procedural constructs
 - Expressions in ORDER BY
 - Savepoints
 - Update through unions and joins

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▼ SQL99 Overview

Multipart standard:

- **SQL/Framework** (Part 1)
 - Overview and conformance clause
- **SQL/Foundation** (Part 2)
 - The basics: types, schemas, tables, views, query and update statements, expressions, security model, predicates, assignment rules, transaction management and so forth
- **SQL/CLI** (Call Level Interface) (Part 3)
 - No preprocessing of SQL statements necessary
- **SQL/PSM** (Persistent Stored Modules) (Part 4)
 - Extensions to SQL to make it procedural
- **SQL/Bindings** (Part 5)
 - Dynamic, embedded, direct invocation

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▼ SQL99 Framework Overview

- **Overview**
 - Provides an overview of the complete standard
- **Conformance**
 - Contains conformance clause

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SQL99 Foundation Overview

- All of SQL/92 functionality
 - Schemas
 - Different kinds of joins
 - Temporary tables
 - CASE expressions
 - Scrollable cursors
 - ...
- New built-in data types for increased modeling power
 - Boolean
 - Large objects (LOBs)
- Enhanced update capabilities
 - Increase expressive powers
 - Update/delete through unions
 - Update/delete through joins
- Other relational extensions to increase modeling and expressive power
 - Additional predicates (FOR ALL, FOR SOME, SIMILAR TO)
 - Extensions to cursors (sensitive cursor, holdable cursor)
 - Extensions to referential integrity (RESTRICT)
 - Extensions to joins

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SQL99 Foundation Overview...

- Triggers
 - Enhances integrity mechanism (active DBMS)
 - Different triggering events: update/delete/insert
 - Optional condition
 - Activation time: before or after
 - Multi-statement action
 - Several triggers per table
 - Condition and multi-statement action per each row or per statement
- Roles
 - Enhanced security mechanisms
 - GRANT/REVOKE privileges to roles
 - GRANT/REVOKE roles to users and other roles

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SQL99 Foundation Overview

- Recursion
 - Increase expressive power
 - Linear (both direct and mutual) recursion
 - Stop conditions
 - Different search strategies (depth first, breadth first)
- Savepoints
 - Enhances user-controlled integrity
 - Savepoint definition
 - Roll back to savepoint
 - Nesting
- OLAP extensions
 - Enhances query capabilities
 - CUBE
 - ROLLUP
 - Expressions in ORDER BY

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SQL99 Foundation Overview

- Object-relational Extensions
 - **Extensibility**: application specific data types "understandable" by DBMS
 - **Increase modeling power** (complex objects): increase the range of applications
 - **Reusability**: sharing existing type libraries
 - **Integration**: enable integration of OO and relational concepts in a single language
- User-defined types
 - Distinct types
 - Strong typing
 - Type-specific behavior
 - Structured types
 - Strong typing
 - Type-specific behaviors
 - encapsulation
 - Value substitutability
 - Polymorphic routines
 - Dynamic binding (run-time function dispatch)
 - Compile-time type checking

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SQL99 Foundation Overview

- Collection types
 - Arrays
- Row types
 - Like record structures in programming languages
 - Type of rows in tables
 - Nesting (rows with row-valued fields)
- Reference types
 - Support "object identity"
 - Navigational access (path expressions)

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SQL99 Foundation Overview

- User-defined functions
 - SQL and external functions
 - Overloaded functions
 - User-defined paths
 - Compile time type checking
 - Static binding
- User-defined procedures
 - SQL and external procedures
 - NO overloading
 - Input and output parameters
 - Result sets
 - Static binding
- User-defined methods
 - Describe a user-defined type behavior
 - SQL and external methods
 - Overloading and overriding
 - Compile time checking
 - Late binding (dynamic dispatch)

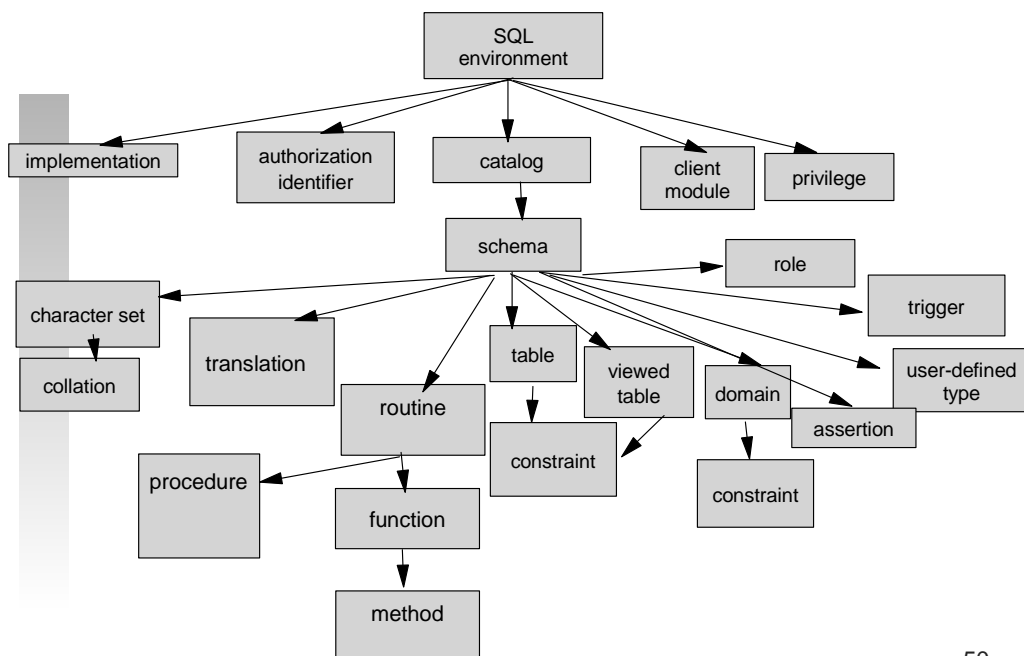
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SQL99 Foundation Overview

- Subtables (table hierarchies)
 - Increase modeling power and expressive power of queries
 - Means to model collection hierarchies or object extents
 - CREATE/DROP subtable
 - CREATE/DROP subview
 - Object "identity" by means of references
 - Queries on a table operate on subtables as well
 - "Object-like" manipulation through references and path expressions
 - Extensions to authorization model to support "object-like" manipulation

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Database Objects



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▼ Catalogs and Schemas

- SQL objects (i.e., tables, views, ...) are contained in schemas
- Schemas are contained in catalogs
- Each schema has a single owner
- Objects can be referenced with explicit or implicit catalog and schema name

FROM people --unqualified name
FROM sample.people --partially qualified name
FROM cat1.sample.people --fully qualified name

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▼ Schema Manipulation Language

- Syntax for creating objects
- Syntax for dropping or revoking with two behaviors
 - RESTRICT disallows the operation if database objects exist that reference the object being dropped or revoked
 - CASCADE propagates the change (in some form) to database objects that may reference the object being dropped or revoked
 - DROP TABLE => drop assertion that references the table
 - DROP DOMAIN => columns that reference the domain take on the data type, constraints, and the default value of the domain
- Syntax for altering objects
 - Table
 - Add/drop column
 - Alter column default and scope
 - Add/drop constraints
 - Domain
 - Set/drop default
 - Add/drop constraint
 - User-defined type
 - Add/drop attribute
 - Add/drop method
 - SQL-invoked routines
 - Alter routine characteristics

52

▼ Identifiers

- Up to 128 characters
- Lower case characters may be used in identifiers and key words
 - These lower case characters are considered to be their upper case counterparts
- Delimited identifiers are case sensitive
 - Allow wider range of characters

```
CREATE TABLE "People Hobbies"
```

```
...
```

53

▼ Information Schema Tables

- A set of views describing the metadata contained in a catalog
 - Exist in the INFORMATION_SCHEMA schema
 - Are fully defined (column names, data types, and semantics)
 - May be queried by users
 - Are read-only
 - Reflect database objects that the user owns or for which the user has some privilege

```
TABLES  
COLUMNS  
VIEWS  
DOMAINS  
etc
```

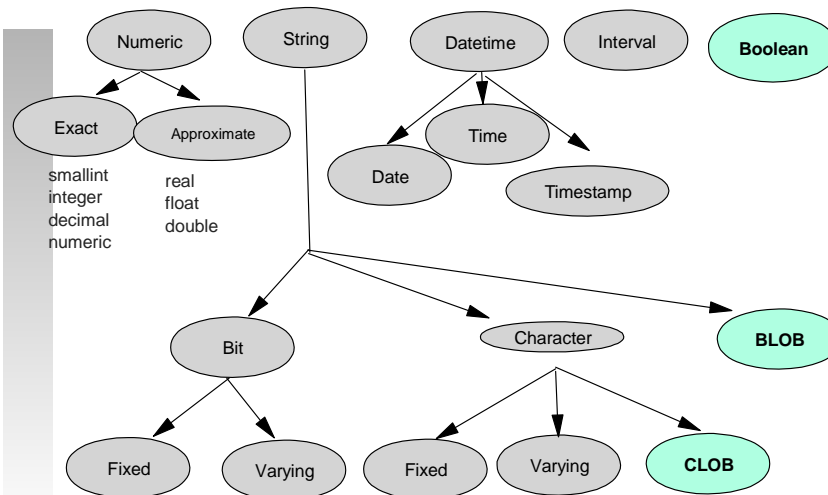
54

▼ Data Types

- Predefined types
 - Numeric
 - String
 - BLOB
 - Boolean
 - Datetime
 - Interval
- Constructed atomic types
 - Reference
- Constructed composite types
 - Collection: Array
 - Row
- User-defined types
 - Distinct type
 - Structured type

55

▼ Predefined Types

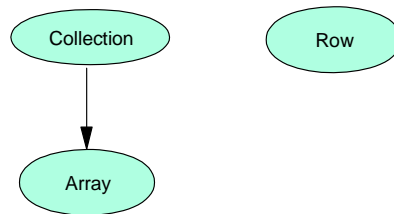


56

▼ Constructed Types

- Atomic
 - Currently, only one: *reference type*

- Composite



More collection types likely in SQL4

57

▼ Varying Length Character String

CHARACTER VARYING (150)

VARCHAR (150)

- The number of characters in a value may vary, from 0 to some implementation-defined maximum
- Additional functions

CHARACTER_LENGTH

OCTET_LENGTH

- Fully compatible with fixed-length character strings
 - **Comparison** is allowed between character strings, regardless of whether they are varying or fixed
 - **Assignment** is allowed between character strings, regardless of whether they are varying or fixed
- Character string literals are fixed-length character strings (i.e., CHAR)

58

▼ Bit Strings

BIT (32)

BIT VARYING (1024)

- String of binary digits, very much like character strings

- ▶ Literals

B'101010'

X'123456789ABCDEF' -- hex digits

- ▶ Function

BIT_LENGTH (bs)

- ▶ Fixed and varying-length bit strings are fully compatible with one another
 - **Comparison** is allowed between bit strings, regardless of whether they are varying or fixed
 - **Assignment** is allowed between bit strings, regardless of whether they are varying or fixed

59

▼ String Operations

- Concatenation

'abc' || 'xyz'

'abcxyz'

b'10' || b'01'

b'1001'

- Position

POSITION ('bc' IN 'abcd')

2

- Substring

SUBSTRING ('Alexandre' FROM 4 FOR 1) 'x'

SUBSTRING (b'1011' FROM 2 FOR 2) b'01'

- Upper/lower case transformation

UPPER ('Hello')

'HELLO'

LOWER ('HI')

'hi'

- Elimination of blanks and other characters

TRIM (LEADING ' ' FROM ' NELSON ') 'NELSON'

TRIM (TRAILING ' ' FROM ' NELSON ') 'NELSON'

TRIM (BOTH ' ' FROM ' NELSON ') 'NELSON'

TRIM (BOTH 'N' FROM ' NELSON ') 'ELSO'

60

▼ Character Sets

- May be defined by a standard, by an implementation, or (in a limited fashion) by a user
 - Must have the space character
 - Comparisons and string operators require operands with the same character set
- Character set may be specified for literals, or for characteristics of CHAR and VARCHAR types
- Character set for identifiers: SQL_IDENTIFIER

```
_SPANISH '?Como Esta¿'          -- character string
```

```
name CHAR(20)                    -- column data type
  CHARACTER SET BRAZILIAN
```

- In SQL92, user could specify character set for identifiers

```
CREATE TABLE                     -- identifier
  _GERMAN Bücher
```

This feature was removed in SQL99

61

▼ SQL99-defined Character Sets

- SQL_CHARACTER
 - 52 upper/lower case simple characters
 - 10 digits
 - 21 special characters
- GRAPHIC_IRV
 - 95 characters of ISO 646:1991
- LATIN1 (aka ISO 8859-1)
- ISO8BIT (aka ACII_FULLL)
- 3 Unicode character sets
 - ISO10646 UTF16, UTF8, and UCS2
- SQL_Text
 - Union of all supported character sets
- SQL_IDENTIFIER
 - Subset of SQL_Text
 - Implicitly used for identifiers

62

▼ Collations

- Set of rules for ordering character strings
 - A character set has a default collation
 - Additional collations may be defined by the implementation or by the user
 - Rules exist to cover the case where operands of a comparison or operator have different collations
 - The use of collations is pervasive
 - Comparison predicate
 - DISTINCT
 - ORDER BY
 - GROUP BY

```
SELECT  Iname, COUNT (*)  
FROM    people  
GROUP BY Iname COLLATE latin1_insensitive;
```

63

▼ Translations and Conversions

- TRANSLATE built-in function is used to change input characters to characters of another character set

```
TRANSLATE (Iname USING german)
```

- CONVERT built-in function is used to change input characters to a different "form-of-use," where form-of-use is defined as "an encoding for representing characters (e.g., fixed length vs. variable length)"

```
CONVERT (Iname USING utf8toutf16)
```

64

▼ Boolean Data Type

- Comprises distinct truth values *true* and *false*
- *unknown* if nulls are allowed
 - SOME and EVERY are functions valid for boolean expressions and boolean result data types

```
SELECT DEPT#, EVERY ( salary > 20000 ) AS all_rich,
       SOME (salary > 20000) AS some_rich
FROM EMP
GROUP BY DEPT#;
```

DEPT#	all_rich	some_rich
J64	false	false
Q05	true	true
M05	false	true

- Boolean comparison:

```
SELECT cname, storename
FROM stores s, customer c
WHERE within(s.zone, c.location) AND --boolean
       overlaps (s.zone, 'California')
```

65

▼ Date, Time, and Timestamp

TYPE	VALUE
DATE	YEAR MONTH DAY
TIME [WITH TIME ZONES]	HOUR MINUTE SECOND (+ fractional digits)
TIMESTAMP [precision] [WITH TIMEZONE]	YEAR MONTH DAY HOUR MINUTE SECOND (+ fractional digits)

DATE
TIME
TIMESTAMP
TIME WITH TIME ZONE
TIMESTAMP (3) WITH TIME ZONE

- Comparisons are only allowed between the same types

66

▼ Date, Time, Timestamp

- ▶ Coordinated universal time (UTC) used to store TIME and TIMESTAMP values
- ▶ WITH TIME ZONE can be specified
Each session has a time zone, which is used if no time zone is explicitly specified
- ▶ Additional functions
CURRENT_DATE
CURRENT_TIME
CURRENT_TIMESTAMP (3)
- ▶ Literals
DATE '1992-06-03'
TIME '13:00:00'
TIME '13:00:00.5+08:00'
TIMESTAMP '1992-06-03 13:00:00'

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▼ Intervals

<u>TYPE</u>	<u>VALUE</u>
year - month	YEAR MONTH
day - time	DAY HOUR MINUTE SECOND (+ fractional digits)

INTERVAL YEAR TO MONTH
INTERVAL HOUR
INTERVAL HOUR TO MINUTE
INTERVAL MINUTE TO SECOND (1)

- May be positive or negative
- Interval qualifier determines the specific fields to be used
- Literals:
INTERVAL '+1-3' YEAR TO MONTH
INTERVAL '-15:15,15' MINUTE TO SECOND (2)
- Comparisons cannot be performed between the two types of intervals

68

Operations on Datetime and Interval Values

- The following operations are supported:

<u>1st operand</u>	<u>operator</u>	<u>2nd operand</u>	<u>result</u>
DATETIME	-	DATETIME	INTERVAL
DATETIME	+	INTERVAL	DATETIME
DATETIME	-	INTERVAL	DATETIME
INTERVAL	+	DATETIME	DATETIME
INTERVAL	+	INTERVAL	INTERVAL
INTERVAL	-	INTERVAL	INTERVAL
INTERVAL	*	number	INTERVAL
INTERVAL	/	number	INTERVAL
number	*	INTERVAL	INTERVAL

69

Data Type Conversions

- Implicit conversions
 - Dynamic SQL
 - UNION and similar operators
- VALUES (10.5), (5.E2), (2)
 - results in data type approximate numeric
- Explicit conversions by means of CAST specification

70

▼ Domains

- Persistent (named) definition of
 - A data type
 - An optional default value
 - An optional set of constraints
 - An optional collating sequence
- Used in place of a data type
- Do not provide strong typing
 - Not true “relational domains”

```
CREATE DOMAIN money AS DECIMAL (7,2);
```

```
CREATE DOMAIN account_type AS CHAR (1)
DEFAULT 'C'
CONSTRAINT account_type_check CHECK ( value IN ('C', 'S', 'M'));
```

```
CREATE TABLE accounts
(account_id INTEGER,
balance money,
type account_type);
```

71

▼ SQL-invoked Routines

- Named persistent code to be invoked from SQL
 - SQL-invoked procedures
 - SQL-invoked functions
 - SQL-invoked methods
- Created directly in a schema or in a SQL-server module
 - schema-level routines
 - module-level routines
- Have schema-qualified 3-part names
- Supported DDL
 - CREATE and DROP statements
 - ALTER statement -- still limited in functionality
 - EXECUTE privilege controlled through GRANT and REVOKE statements
- Described by corresponding information schema views

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▼ SQL-invoked Routines (cont.)

- Have a header and a body
 - Header consists of a name and a (possibly empty) list of parameters.
- Parameters of procedures may specify parameter mode
 - IN
 - OUT
 - INOUT
- Parameters of functions are always IN
- Functions return a single value
 - Header must specify data type of return value via RETURNS clause
- SQL routines
 - Both header and body specified in SQL
- External routines
 - Header specified in SQL
 - Bodies written in a host programming language
 - May contain SQL by embedding SQL statements in host language programs or using CLI

73

▼ SQL-invoked Routines (cont.)

- Advantages of external routines:
 - Can utilize more "complete" languages
 - Can take advantage of existing code libraries
 - Can use widely-accepted languages
- Disadvantages of external routines:
 - Need to learn two different languages (no integrated programming environment)
 - Need to convert between SQL data types and host language data types (loss of type behavior and type checking)
- Advantages of SQL routines:
 - Integrated programming language and programming environment (easier to use)
 - No need for mapping SQL data types to host language types (type behavior and type checking are not lost across the boundary)
- Disadvantages of SQL routines:
 - Not as complete as host languages
 - No wide acceptance

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SQL Routines

- Parameters
 - Must have a name
 - Can be of any SQL data type
- Routine body
 - Consists of a single SQL statement
 - Can be a compound statement: BEGIN ... END
 - Not allowed to contain
 - DDL statement
 - CONNECT or DISCONNECT statement
 - Dynamic SQL
 - COMMIT or ROLLBACK statement

```
CREATE PROCEDURE get_balance(IN acct_id INT, OUT bal
DECIMAL(15,2))
BEGIN
  SELECT balance INTO bal
  FROM accounts WHERE account_id = acct_id;
  IF bal < 100
  THEN SIGNAL low_balance
  END IF;
END
```

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SQL Routines (cont.)

- Routine body
 - RETURN statement allowed only inside the body of a function
 - Exception raised if function terminates not by a RETURN

```
CREATE FUNCTION get_balance( acct_id INT) RETURNS
DECIMAL(15,2)
BEGIN
  DECLARE bal DECIMAL(15,2);
  SELECT balance INTO bal
  FROM accounts
  WHERE account_id = acct_id;
  IF bal < 100 THEN SIGNAL low_balance
  END IF;
  RETURN bal;
END
```

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External Routines

- Parameters
 - Names are optional
 - Cannot be of any SQL data type
 - Permissible data types depend on the host language of the body
- LANGUAGE clause
 - Identifies the host language in which the body is written
- NAME clause
 - Identifies the host language code, e.g., file path in Unix
 - If unspecified, it corresponds to the routine name

```
CREATE PROCEDURE get_balance (IN acct_id INT, OUT bal DECIMAL(15,2))  
LANGUAGE C  
EXTERNAL NAME 'bank\balance_proc'
```

```
CREATE FUNCTION get_balance( IN INTEGER) RETURNS DECIMAL(15,2)  
LANGUAGE C  
EXTERNAL NAME 'usr/McKnight/banking/balance'
```

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External Routines (cont.)

- RETURNS clause may specify CAST FROM clause

```
CREATE FUNCTION get_balance( IN INT)  
RETURNS DECIMAL(15,2) CAST FROM REAL  
LANGUAGE C
```

- C program returns a REAL value, which is then cast to DECIMAL(15,2) before returning to the caller.
- Special provisions to handle null indicators and the status of execution (SQLSTATE)
 - PARAMETER STYLE SQL (is the default)
 - PARAMETER STYLE GENERAL

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External Routines (cont.)

■ PARAMETER STYLE SQL

- ▶ Additional parameters necessary for null indicators, returning function results, and returning SQLSTATE value
- ▶ External language program (i.e., the body) has $2n+4$ parameters for procedures and $2n+6$ parameters for functions where n is the number of parameters of the external routine

```
CREATE FUNCTION get_balance( IN INTEGER)
RETURNS DECIMAL(15,2)) CAST FROM REAL
LANGUAGE C
EXTERNAL NAME 'bank\balance'
PARAMETER STYLE SQL
void balance (int* acct_id,
float* rtn_val,
int* acct_id_ind,
int* rtn_ind,
char* sqlstate[6],
char* rtn_name [512],
char* spc_name [512],
char* msg_text[512])
{
...
}
```

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External Routines (cont.)

■ PARAMETER STYLE GENERAL

- ▶ No additional parameters
- ▶ External language program (i.e., the body) must have exactly the same number of parameters
- ▶ Cannot deal with null values
 - Exception is raised if any of the arguments evaluate to null
- ▶ Value returned in an implementation-dependent manner

```
CREATE FUNCTION get_balance( IN INTEGER)
RETURNS DECIMAL(15,2)) CAST FROM REAL
LANGUAGE C
EXTERNAL NAME 'bank\balance'
PARAMETER STYLE GENERAL
```

```
float* balance (int* acct_id)
{
...
}
```

80

▼ Routine Characteristics

- DETERMINISTIC or NOT DETERMINISTIC
 - DETERMINISTIC (default)
 - Routine is expected to return the same result/output values for a given list of input values. (However, no checks are done at run time.)
 - NOT DETERMINISTIC routines not allowed in
 - Constraint definitions
 - Assertions
 - In the condition part of CASE expressions
 - CASE statements
- RETURNS NULL ON NULL INPUT or CALLED ON NULL INPUT (default)
 - RETURNS NULL ON NULL INPUT
 - An invocation returns null result/output value if any of the input values is null without executing the routine body
- DYNAMIC RESULT SETS <unsigned integer>
 - Valid on procedures only (SQL or external)
 - Defined number of result sets that the procedure is allowed to return
 - If unspecified, DYNAMIC RESULT SETS 0 is implicit

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▼ Routine Characteristics (cont.)

- CONTAINS SQL, READS SQL DATA, or MODIFIES SQL DATA
 - External routines may in addition specify NO SQL
 - CONTAINS SQL (default)
 - For SQL routines -- check may be done at routine creation time
 - For both SQL and external routines -- exception raised if a routine attempts to perform actions that violate the specified characteristic
 - Routines with MODIFIES SQL DATA not allowed in
 - Constraint definitions
 - Assertions
 - Query expressions other than table value constructors
 - Triggered actions of BEFORE triggers
 - Condition part of CASE expressions
 - CASE statements
 - searched delete statements
 - search condition of searched update statements (are allowed in SET clause)

82

▼ Privilege Requirements

- SQL routine
 - ▶ Creator must have all the privileges required for execution of the routine body
 - ▶ Creator gets the EXECUTE privilege on the routine automatically
 - GRANT OPTION on EXECUTE privilege given if creator has GRANT OPTION on all the privileges required for execution of the routine body
 - Creator loses the GRANT OPTION if at any time he/she loses any of the privileges required for successful execution of the routine body
 - ▶ Routine is dropped If at any time the creator loses any of the privileges required for execution of the routine body (in CASCADE mode)
- External routine
 - ▶ Creator gets the EXECUTE privilege with GRANT OPTION on the routine automatically

83

▼ Routine Overloading

- Overloading -- multiple routines with the same unqualified name

S1.F (p1 INT, p2 REAL)
S1.F (p1 REAL, p2 INT)
S2.F (p1 INT, p2 REAL)

- Within the same schema

- ▶ Every overloaded routine must have a unique signature, i.e., different number of parameters or different types for the same parameters

S1.F (p1 INT, p2 REAL)
S1.F (p1 REAL, p2 INT)

- Across schemas

- ▶ Overloaded routines may have the same signature

S1.F (p1 INT, p2 REAL)
S2.F (p1 INT, p2 REAL)

- Only functions can be overloaded. Procedures cannot be overloaded.

84

▼ Specific Names

- Uniquely identifies each routine in the database
 - If unspecified, an implementation-dependent name is generated.

```
CREATE FUNCTION get_balance( acct_id INTEGER)
RETURNS DECIMAL(15,2)
SPECIFIC func1
BEGIN
...
RETURN ...;
END
```

- Can only be used to identify the routine in ALTER, DROP, GRANT, and REVOKE statements

```
DROP SPECIFIC FUNCTION func1 RESTRICT;
```
- DDL statements can also identify a routine by providing the name and the list of parameter types

```
DROP FUNCTION get_balance(INTEGER) CASCADE;
```
- Cannot be used to invoke a routine

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▼ Routine Invocation

- Procedure -- invoked by a CALL statement:

```
CALL get_balance (100, bal);
```

- Function -- invoked as part of an expression:

```
SELECT account_id, get_balance (account_id)
FROM accounts
```

- Requires the invoker to have EXECUTE privilege on the routine -- otherwise no routine will be found for the invocation
 - **It is not an authorization violation!!!**

86

▼ Subject Routine Determination

- Decides the function to invoke for a given invocation based on the
 - Compile-time data types of all arguments
 - Type precedence list of the data types of the arguments
 - SQL path
- Always succeeds in finding a unique subject function, if one exists.
- Type precedence list is a list of data type names
 - Predefined types -- defined by the standard based on increasing precision/length
 - **SMALLINT**: SMALLINT, INTEGER, DECIMAL, NUMERIC, REAL, FLOAT, DOUBLE
 - **CHAR**: CHAR, VARCHAR, CLOB
 - User-defined types is determined by the subtype-supertype relationship
 - if B is a subtype of A and C is a subtype of B, then the type precedence list for C is (C, B, A).

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▼ Subject Routine Determination (cont.)

- Path is a list of schema names.
 - Can be specified during the creation of a schema, SQL-client module, or a SQL-server module
- CREATE SCHEMA** schema5
PATH schema1,schema3
...;
- Every session has a default path, which can be changed using the SET statement.

SET PATH 'schema1, schema2'

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Subject Routine Determination (cont.)

1. Determine the set of candidate functions for a given function invocation, $F(a_1, a_2, \dots, a_n)$:
 - ▶ Every function contained in S_1 that has name F and has n parameters if the function name is fully qualified, i.e., the function invocation is of the form $S_1.F(a_1, a_2, \dots, a_n)$, where S_1 is a schema name.
 - ▶ Every function in every schema of the applicable path that has name F and has n parameters if the function name is not fully qualified.
2. Eliminate unsuitable candidate functions
 - a. The invoker has no EXECUTE privilege
 - b. The data type of i -th parameter of the function is not in the type precedence list of the static type of the i -th argument (for parameter)
3. Select the best match from the remaining functions
 - a. Examine the type of the 1st parameter of each function and keep only those functions such that the type of their 1st parameter matches best the static type of the 1st argument (i.e., occurs earliest in the type precedence list of the static type of the argument), and eliminate the rest.
 - b. Repeat Step b for the 2nd and subsequent parameters. Stop whenever there is only one function remaining or all parameters are considered.
4. Select the "subject function"
 - a. From the remaining functions take the one whose schema appears first in the applicable path (if there is only one function, then it is the "subject function")

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Subject Routine Determination (cont.)

- Assume Y is a subtype of X . Assume the following three functions (with specific names F_1 , F_2 , and F_3):

F_1 : $F(p_1 X, p_2 Y)$
 F_2 : $F(p_1 Y, p_2 Y)$
 F_3 : $F(p_1 X, p_2 REAL)$

- The subject function for $F(y,y)$ where the static type of y is Y is F_2 .
- Now, assume the following three functions (with specific names F_4 , F_5 , and F_6):

F_4 : $F(p_1 X, p_2 Y)$
 F_5 : $F(p_1 X, p_2 X)$
 F_6 : $F(p_1 X, p_2 REAL)$

- The subject function for $F(y,y)$ where the static type of y is Y is F_4 .

90

▼ Dropping Routines

- Routines can be dropped using DROP statement.

```
DROP FUNCTION get_balance(INTEGER) CASCADE;  
DROP FUNCTION get_balance(INTEGER) RESTRICT;
```

- Normal RESTRICT/CASCADE semantics applies with respect to dependent objects:
 - Routines
 - Views
 - Constraints
 - Triggers

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▼ Altering Routines

- Routines can be altered with ALTER statement.
- Allowed only for external routines and for the following routine characteristics:
 - Language
 - Parameter style
 - SQL data access indication
 - Null behavior
 - Dynamic result set specification
 - NAME clause

```
ALTER FUNCTION get_balance (INTEGER)  
READS SQL DATA  
RESTRICT
```

- RESTRICT is the only allowed option, i.e., a routine cannot be altered if there are any dependent objects.

92

▼ Object-Relational Support

- The queries have changed
 - ▶ How many programmers with skills in SQL and Objects are working on the most profitable product?
 - ▶ How many accidents happened within 0.2 miles from highway exits which damaged the front bumpers of red cars?
 - ▶ Tell me the sales regions in which my top 5 products had a sales drop of more than 10%.
 - ▶ Give me the marketing campaigns that used images of sunny beaches with white sands.

93

▼ Object-Relational Support: Motivation

- Database systems provide
 - ▶ A set of types used to represent the data in the application domain
 - ▶ A set of operations (functions) to manipulate these types

TYPE	FUNCTION
INTEGER	+, -, /, *, ...
CHAR	SUBSTRING, CONCAT, ...
DATE	DAY, MONTH, YEAR, ...

- Increasing need for extension
 - ▶ New types required to better represent the application domain
 - ▶ New operations (functions) required to better reflect the behavior of the types

TYPE	FUNCTION
MONEY	+, -, INTEREST, ...
CHAR	CONTAINS, SPELLCHECKING, ...
IMAGE	WIDTH, HEIGHT, THUMBNAIL, ...

94

▼ Major Extensions in SQL99

- Mechanism for "users" to extend the database with application **"objects"** (specific types and their behavior - functions/methods)
 - ▶ **User Defined Types (UDTs)**: Text, Image, CAD/CAM Drawing, Video ...
 - ▶ **User Defined Functions (UDFs)**: Contains, Display, Rotate, Play, ...
- Support for storage/manipulation of **large data types**
 - ▶ **Large Object Support (LOBs)**: Binary, Character
- Mechanism to improve the DB integrity and to allow checking of **business rules** inside the DBMS
 - ▶ **Triggers**: Auditing, Cross-Referencing, Alerts ...
- Means to express **complex data relationships** such as hierarchies, bills-of-material, travel planning ...
 - ▶ **Recursion**
 - ▶ **Update through UNION and JOIN**
 - ▶ **Common Table Expressions**

Upward compatible extension of SQL to guarantee application portability and database independence!

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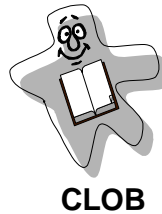
▼ Object-Relational Support

- Large Objects (LOBs)
 - ▶ Binary
 - ▶ Character
- User-Defined Data Types
 - ▶ Distinct types
 - ▶ Structured types
- Type Constructors
 - ▶ Row types
 - ▶ Reference types
- Collection Types
 - ▶ Arrays
- User-Defined Methods, Functions, and Procedures
- Typed tables and views
 - ▶ Table hierarchies
 - ▶ View hierarchies (object views)

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What are Large Objects (LOBs)?

- **LOBs** are a new set of data types
 - LOBs store strings of up to gigabytes
- There are 2 new data types
 - BLOB - Binary Large Object
 - Useful for Audio, Image data
 - CLOB - Character Large Object
 - For character data



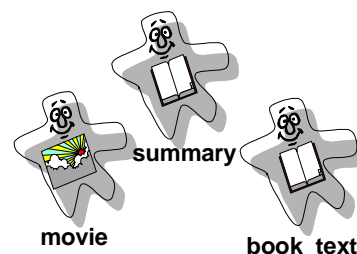
Object	Size
Check Image	45K
Text	30-40 K/page
Small Image	30-40K
Large Image	200K-3M
Color Image	20-40M
Radiology Image	40-60M
Video	1G/Hour
High Res Video	3G/Hour
High Definition TV	200M/sec

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Large Object Data Types

- Maintained directly in the database
- Not in "external files"
- LOB size can be specified at column definition time (in terms of KB, MB, or GB)

```
CREATE TABLE Booktable  
(title          VARCHAR(200),  
 book_id       INTEGER,  
 summary       CLOB(32K),  
 book_text     CLOB(20M),  
 movie         BLOB(2G))
```



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▼ How do you Use LOBS?



99

▼ How do you Use LOBS?

- LOBs may be retrieved, inserted, updated like any other type
 - You must acquire buffers large enough to store the LOBs
 - This may be difficult for very large LOBs

```
EXEC SQL
SELECT summary, book_text, movie
INTO :bigbuf, :biggerbuf, :massivebuf
FROM BOOKTABLE
WHERE title = 'Moby Dick';
```

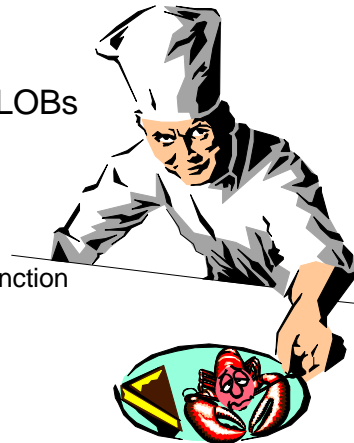
Booktable:	
title	VARCHAR(200)
book_id	INTEGER
summary	CLOB(32K)
book_text	CLOB(20M)
movie	BLOB(2G)



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Large Object Data Types

- LOBs are excluded from some operations:
 - ▶ Greater Than and Less Than operations
 - ▶ Primary, unique, and foreign keys
 - ▶ GROUP BY and ORDER BY
 - ▶ UNION operator, INTERSECT, EXCEPT
 - ▶ Joins (as join columns)
- Some operations are supported for LOBs
 - ▶ Retrieve value (or partial value)
 - ▶ Replace value
 - ▶ LIKE predicate
 - ▶ Concatenation
 - ▶ SUBSTRING, POSITION, and LENGTH function
 - ▶ TRIM
 - ▶ OVERLAY



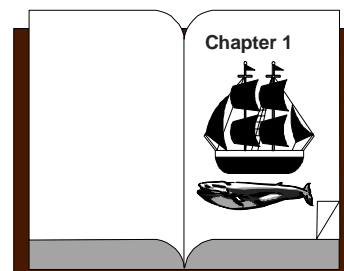
101

LOB Functions

- Functions that support LOBs
 - ▶ CONCATENATION *string1* || *string2*
 - ▶ SUBSTRING(*string* FROM *start* FOR *length*)
 - ▶ LENGTH(*expression*)
 - ▶ POSITION(*search-string* IN *source-string*)
 - ▶ NULLIF/COALESCE
 - ▶ TRIM
 - ▶ OVERLAY
 - ▶ **Cast**
 - ▶ **User-defined functions**
 - ▶ LIKE predicate

Booktable:	
title	VARCHAR(200)
book_id	INTEGER
summary	CLOB(32K)
book_text	CLOB(20M)
movie	BLOB(2G)

```
EXEC SQL
SELECT position('Chapter 1' IN book_text)
INTO :int_variable
FROM BOOKTABLE
WHERE title = 'Moby Dick';
```



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▼ GigaByte Buffers? Get real!

- LOBs may be unmanageable in application programs
 - Huge amounts of storage may be needed to buffer their values
 - It may not be possible to acquire contiguous buffers of sufficient size
 - Applications may want to deal with LOBs a *piece at a time*
 - In the above example, multiple SELECTs would be required
- SQL99 provides *locators* to make LOB access manageable



```
EXEC SQL
SELECT summary, book_text, movie
INTO :bigbuf, :biggerbuf, :massivebuf
FROM BOOKTABLE
WHERE title = 'Moby Dick';
```

```
BOOKTABLE:
title      VARCHAR(200)
book_id    ROWID
summary    CLOB(32K)
book_text  CLOB(20M)
movie      BLOB(2G)
```

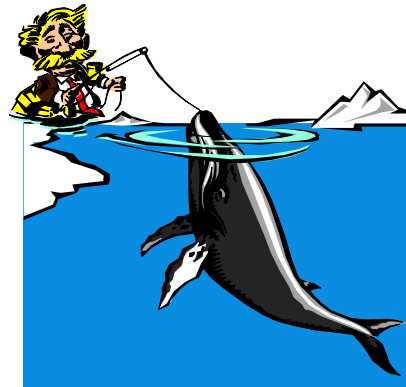
103

▼ Locators

- *locator*: 4-byte value stored in a host variable that a program can use to refer to a LOB value
 - Application declares *locator variable*, and then may set it to refer to the current value of a particular LOB
 - A locator may be used anywhere a LOB value can be used

```
EXEC SQL BEGIN DECLARE
SECTION;
SQL TYPE IS BLOB_LOCATOR
movie_loc;
EXEC SQL END DECLARE SECTION;

EXEC SQL
SELECT movie
INTO :movie_loc
FROM BOOKTABLE
WHERE title = 'Moby Dick'
```



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Locators on LOB Expressions

- **Locators** may also represent LOB expressions
 - A LOB expression is any expression that refers to a LOB column or results in a LOB data type
 - LOB functions may be part of LOB expressions
 - LOB expressions may even reference other locators
 - LOB expressions may be VERY complicated
 - The above example associates only the first chapter with a locator

```
SELECT
  SUBSTRING(book_text,
    POSITION('Chapter 1' IN book_text),
    POSITION('Chapter 2' IN book_text) -
    POSITION('Chapter 1' IN book_text)
  )
FROM Booktable
INTO :Chapt1Loc
WHERE title = 'Moby Dick';
```



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Locators can be holdable

- **HOLD locator**
 - Maintains the LOB value and locator after the commit of a transaction
- **FREE locator**
 - Frees a locator and its LOB value

```
SELECT book_text
INTO :LOB_locator
FROM Booktable WHERE title =
'Moby Dick';

HOLD LOCATOR :LOB_locator;

COMMIT;

INSERT INTO my_favor_books
VALUES (... , :LOB_locator, ...)
```



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▼ **HOLD LOCATOR Statement**

- Locators, when created, are marked valid. A valid locator normally becomes invalid at the end of transaction (when COMMIT or ROLLBACK happens).
- HOLD LOCATOR statement marks a host variable or host parameter locator as holdable:

HOLD LOCATOR :emp;

- Holdable locators remain valid across transaction boundaries that end successfully.
- Not allowed for parameters or result of external routines.

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▼ **FREE LOCATOR Statement**

- FREE LOCATOR statement marks a valid host variable or host parameter locator as invalid:

FREE LOCATOR :emp;

- All valid locators are marked invalid if the transaction ends with ROLLBACK statement.

108

▼ User-defined types

- User-defined data types
 - User-defined, named type representing entities
 - employee, project, money, polygon, image, text, language, format, ...
- User-defined methods and functions (operators)
 - User-defined operation representing the behavior of entities in the application domain
 - hire, appraisal, convert, area, length, contains, ranking, ...
- Definition:
 - User-defined data type
 - Name
 - Representation
 - Relationship to other types
 - User-defined method (and function)
 - Name
 - Signature (i.e., parameter list)
 - Result
 - Implementation

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▼ User-defined Types: Key Features

- **New functionality**
 - Users can indefinitely increase the set of provided types
 - Users can indefinitely increase the set of operations on types and extend SQL to automate complex operations/calculations
- **Flexibility**
 - Users can specify any semantics and behavior for a new type
- **Consistency**
 - Strong typing insures that functions are applied on correct types
- **Encapsulation**
 - Applications do not depend on the internal representation of the type
- **Performance**
 - Potential to integrate types and functions into the DBMS as "first class citizens"

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▼ User-defined Types: Benefits

- **Simplified application development**
 - ▶ **Code Re-use** - allows reuse of common code
 - ▶ **Overloading and overriding** - makes application development easier -- single function name for a set of operations on different types, e.g., area of circles, triangles, and rectangles
- **Consistency**
 - ▶ Enables definition of standard, **reusable code shared** by all applications (guarantee consistency across all applications using type/function)
- **Easier application maintenance**
 - ▶ **Changes are isolated**: if application model changes, only the corresponding types/functions need to change instead of code in each application program

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▼ User-defined Distinct Types

```
CREATE TABLE RoomTable (  
RoomID      CHAR(10),  
RoomLength  INTEGER,  
RoomWidth   INTEGER,  
RoomArea    INTEGER,  
RoomPerimeter INTEGER);
```

```
UPDATE RoomTable  
SET RoomArea = RoomLength;  
No Error Results
```

- **Before SQL99, columns could only be defined with the existing built-in data types**
 - ▶ There was no strong typing
 - ▶ Logically incompatible variables could be assigned to each other

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▼ User-defined Distinct Types

```
CREATE TYPE plan.roomtype
AS CHAR(10) FINAL;

CREATE TYPE plan.meters
AS INTEGER FINAL;

CREATE TYPE plan.squaremeters
AS INTEGER FINAL;

CREATE TABLE RoomTable (
RoomID          plan.roomtype,
RoomLength      plan.meters,
RoomWidth       plan.meters,
RoomPerimeter   plan.meters,
RoomArea        plan.squaremeters);
```

```
UPDATE RoomTable
SET RoomArea =
RoomLength;
```

ERROR

```
UPDATE RoomTable
SET RoomLength =
RoomWidth;
```

NO ERROR RESULTS

Each UDT is logically incompatible with all other type

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▼ User-defined Distinct Types

- Based on name equivalence (strongly typed)
 - Renamed type, with different behavior than its source type.
 - Shares internal representation with its source type
 - Source and distinct type are not directly comparable

```
CREATE TYPE US_DOLLAR AS DECIMAL (9,2) FINAL
```

- Operations defined on distinct types (behavior)
 - Comparison operators
 - Can be defined based on the comparison of their source type
 - Casting
 - Used to explicitly cast instances of the distinct type and instances of source type to and from one another
 - Used to obtain "literals"
 - Methods and functions
 - No inheritance or subtyping

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▼ User-defined Structured Types

- User-defined, complex data types
 - Can be used as [column types and/or table types](#)
- Column Types
 - E.g., text, image, audio, video, time series, point, line,...
 - For modeling new kinds of *facts* about enterprise entities
 - [Enhanced infrastructure for SQL/MM](#)
- Row Types
 - Types and functions for rows of tables
 - E.g., employees, departments, universities, students, ...
 - For modeling *entities* with *relationships* & *behavior*
 - [Enhanced infrastructure for business objects](#)

```
CREATE TYPE employee
AS
(id    INTEGER,
name  VARCHAR (20))
```

stuff1	stuff2	emp
...	...	id name
oid	id	name
...

Column Type

Row Type

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▼ Structured Types: Example

```
CREATE TYPE address AS
(street    CHAR (30),
city      CHAR (20),
state     CHAR (2),
zip       INTEGER) NOT FINAL
```

```
CREATE TYPE bitmap AS BLOB FINAL
```

```
CREATE TYPE real_estate AS
(owner     REF (person),
price     money,
rooms     INTEGER,
size      DECIMAL(8,2),
location  address,
text_description text,
front_view_image bitmap,
document  doc) NOT FINAL
```

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▼ Use of Structured Types

- Wherever other (predefined data) types can be used in SQL
 - ▶ Type of attributes of other structured types
 - ▶ Type of parameters of functions, methods, and procedures
 - ▶ Type of SQL variables
 - ▶ Type of domains or columns in tables

```
CREATE TYPE address AS (street CHAR (30), ...) NOT FINAL
CREATE TYPE real_estate AS (... location address, ...) NOT FINAL
```

- To define tables and views

```
CREATE TABLE properties OF real_estate ...
```

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▼ Methods

- What are methods?
 - ▶ SQL-invoked functions "attached" to user-defined types
- How are they different from functions?
 - ▶ Implicit SELF parameter (called subject parameter)
 - ▶ Two-step creation process: signature and body specified separately.
 - ▶ Must be created in the type's schema
 - ▶ Different style of invocation (UDT value.method(...))

```
CREATE TYPE employee AS
(name          CHAR(40),
base_salary   DECIMAL(9,2),
bonus         DECIMAL(9,2))
INSTANTIABLE NOT FINAL
METHOD salary() RETURNS DECIMAL(9,2);
```

```
CREATE METHOD salary() FOR employee
BEGIN
....
END;
```

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▼ Methods (cont.)

- Two kinds of methods:
 - **Original** methods: methods attached to super type
 - **Overriding** methods: methods attached to subtypes

```
CREATE TYPE employee AS
(name          CHAR(40),
base_salary   DECIMAL(9,2),
bonus         DECIMAL(9,2))
INSTANTIABLE NOT FINAL
METHOD salary() RETURNS DECIMAL(9,2);
```

```
CREATE TYPE manager UNDER employee AS
(stock_option INTEGER)
INSTANTIABLE NOT FINAL
OVERRIDING METHOD salary() RETURNS DECIMAL(9,2), -- overriding
METHOD vested() RETURNS INTEGER             -- original;
```

- Signature of an overriding method must match with the signature of an original method, except for the subject parameter.

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▼ Methods (cont.)

- Invoked using dot syntax (assume dept table has mgr column):

```
SELECT mgr.salary() FROM dept;
```

- Subject routine determination picks the "best" method to invoke.
 - Same algorithm as used for regular functions
 - SQL path is temporarily set to a list with the schemas of the supertypes of the static type of the self argument.
- Dynamic dispatch executed at runtime
 - Overriding methods considered at execution time
 - Overriding method with the best match for the dynamic type of the self argument is selected.
 - Schema evolution affects the actual method that gets invoked. If there is a new overriding method defined it may be picked for execution.

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▼ Creating Structured Types

- System-supplied constructor function
 - address () -> address or real_estate () -> real_estate
 - Returns new instance with attributes initialized to their default
- NEW operator
 - NEW <method name> <list of parameters>
 - Invokes constructor function before invoking method
- INSERT statement against a typed table

CREATE TABLE properties OF real_estate ...

INSERT INTO properties VALUES (:owner, money (350000), 15, 4500, NEW address ('1543 3rd Ave. North, Sacramento, CA 93523') ...)

SELECT owner, price FROM properties
WHERE address = gen_address (address(), '1543 3rd Ave. North, Sacramento, CA 93523')

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▼ Uninstantiable Types

- Structured types can be uninstantiable
 - Like abstract classes in OO languages
 - No system-supplied constructor function is generated
 - Type does not have instances of its own
 - Instances can be defined on subtypes
- By default, structured types are instantiable
- Distinct types are always instantiable

```
CREATE TYPE person AS
(name      VARCHAR (30),
address   address,
sex       CHAR (1)) NOT INSTANTIABLE NOT FINAL
```

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▼ Manipulating Attributes

- Observer and mutator methods are used to access and modify attributes
 - Automatically generated when type is defined

```
CREATE TYPE address AS (street CHAR (30), city CHAR (20), state CHAR (2), zip INTEGER) NOT FINAL
```

```
address_expression.street () -> CHAR (30)
address_expression.city () -> CHAR (20)
address_expression.state () -> CHAR (2)
address_expression.zip () -> INTEGER
address_expression.street (CHAR (30)) -> address
address_expression.city (CHAR (20)) -> address
address_expression.state (CHAR (2)) -> address
address_expression.zip (INTEGER) -> address
```

```
SELECT location.street, location.city (), location.state, location.zip ()
FROM properties
WHERE price < 100000
```

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▼ Manipulating Attributes

- Queries over type tables access attributes (columns)
- Update statements on typed tables modify attributes

```
CREATE TABLE properties OF real_estate ...
```

```
SELECT owner, price
FROM properties
WHERE address = NEW address '1543 3rd Ave. North,
Sacramento, CA 93523')
```

```
UPDATE properties
SET price = 350000
WHERE address = new address '1543 3rd Ave. North,
Sacramento, CA 93523')
```

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▼ Dot Notation

- "Dot" notation must be used to invoke methods (e.g., to access attributes)
- Methods without parameters do not require use of "()"

```
DECLARE r  real_estate;
...
SET r.size = 2540.50;    -- same as r.size (2540.50)
...
SET ... = r.location.state; -- same as r.location().state()
SET r.location.city = 'LA'; -- same as r.location(r.location.city('LA'))
```

- Support for several 'levels' of dot notation (a.b.c.d.e)
- Allow "navigational" access to structured types
- Dot notation does not 'reveal' physical representation (keeps encapsulation)

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▼ Initializing Instances: Constructor

- Instances are generated by the system-provided constructor function
 - Attributes are initialized with their default values
- Attributes are modified (further initialized) by invoking the mutator functions

```
BEGIN
  DECLARE re real_estate;
  SET re = real_estate();    -- generation of a new instance
  SET re.rooms = 12;        -- initialization of attribute rooms
  SET re.size = 2500;       -- initialization of attribute size
END

BEGIN
  DECLARE re real_estate;
  SET re = real_estate().rooms (12).size (2500); -- same as above
END
```

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Initializing Instances: NEW Operator

- Users can define any number of "initializer" methods and invoke them with NEW operator

```
CREATE TYPE real_estate AS ( ... )
METHOD real_estate (r INTEGER, s DECIMAL(8,2)) RETURNS real_estate

CREATE METHOD real_estate (r INTEGER, s DECIMAL(8,2)) RETURNS
real_estate
BEGIN
    SET self.rooms = r;
    SET self.size = s;
    RETURN re;
END

BEGIN
    DECLARE re real_estate;
    SET re = NEW real_estate(12, (2500);    -- same as previously
END
```

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Manipulating Structured Types

- Structured types are manipulated by invoking methods and functions defined on them
 - May be invoked anywhere scalar values are allowed in SQL

```
INSERT INTO properties
VALUES (:owner, us_dollar (300000), 15, 4650, NEW address
('2225 Coral Drive', 'San Jose', 'CA', 95125), ...);

UPDATE properties
SET price = US_dollar (0.9 x amount (price))
WHERE location.state () = 'CA';

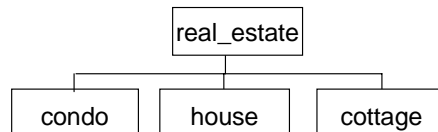
SELECT D_mark (price), owner, location.city ()
FROM properties
WHERE location.zip () = 95453
AND contains (text_description.schools(), 'excellent school
district')
AND contains (front_view_image, 'tree');
```

128

Subtyping and Inheritance

- Structured types can be a subtype of another UDT
- UDTs inherit structure (attributes) and behavior (methods) from their supertypes
 - Single inheritance (multiple inheritance moved to SQL4)
- FINAL and NOT FINAL
 - FINAL types may not have subtypes
 - In SQL99, structured types must be NOT FINAL and distinct types must be FINAL
 - In SQL4, both options will be allowed

```
CREATE TYPE real_estate ... NOT FINAL
CREATE TYPE condo UNDER real_estate ... NOT FINAL
CREATE TYPE house UNDER real_estate ... NOT FINAL
```



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Subtyping and Inheritance

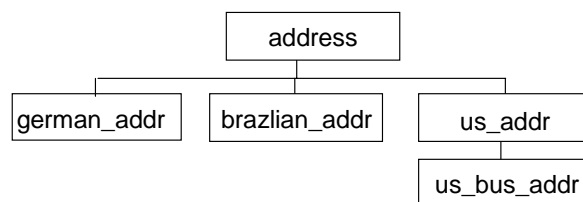
```
CREATE TYPE address AS
(street CHAR (30), city CHAR(20), state CHAR (2), zip INTEGER) NOT FINAL
```

```
CREATE TYPE german_addr UNDER address
(family_name VARCHAR (30) ) NOT FINAL
```

```
CREATE TYPE brazilian_addr UNDER address
(neighborhood VARCHAR (30) ) NOT FINAL
```

```
CREATE TYPE us_addr UNDER address
(area_code INTEGER, phone INTEGER) NOT FINAL
```

```
CREATE TYPE us_bus_addr UNDER address
(bus_area_code INTEGER, bus_phone INTEGER) NOT FINAL
```



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Value Substitutability

- Each row can have a value a different subtype

```
INSERT INTO properties (price, owner, location)
VALUES (US_dollar (100000), REF('Mr.S.White'), NEW us_addr
('1654 Heath Road', 'Heath', 'OH', 45394, ...))
```

```
INSERT INTO properties (price, owner, location)
VALUES (real (400000), REF('Mr.W.Green'), NEW brazilian_addr ('245
Cons. Xavier da Costa', 'Rio de Janeiro', 'Copacabana'))
```

```
INSERT INTO properties (price, owner, location)
VALUES (german_mark (150000), REF('Mrs.D.Black'), NEW
german_addr ('305 Kurt-Schumacher Strasse', 'Kaiserslautern', 'Prof.
Dr. Heuser'))
```

price	owner	location
<code><us_dollar></code> amount 100,000	'Mr. S. White'	<code><us_addr></code> '1654 Heath ...'
<code><real></code> amount 400,000	'Mr. W. Green'	<code><brazilian_addr></code> '245 Cons. Xavier ...'
<code><german_mark></code> amount 150,000	'Mrs. D. Black'	<code><german_addr></code> '305 Kurt-Schumacher ...'

type tag

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Value Substitutability

- An instance of a subtype can be found at runtime (requires dynamic dispatch - late binding)

```
SELECT owner, price.dollar_amount ( )
FROM properties
WHERE price.dollar_amount ( ) < US_dollar (500000)
```

- Will cause the invocation of a different method, depending on the type of money stored in the column PRICE (i.e., US_dollar, CDN_dollar, D_mark, S_frank, real, ...)
- Only methods are dynamically dispatched
 - Functions are statically selected

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Structured Types as Column Types

- 1 **CREATE TYPE envelope (**
 xmin INTEGER,
 ymin INTEGER,
 xmax INTEGER,
 ymax INTEGER);
- 2 **CREATE TYPE geometry (**
 gtype INTEGER,
 refsystem INTEGER,
 tolerance FLOAT,
 area FLOAT,
 length FLOAT,
 mbr **envelope**,
 numparts INTEGER,
 numpoints INTEGER,
 points BLOB(1m),
 zvalue BLOB(500k),
 measure BLOB(500k));
- 3 **CREATE TYPE point UNDER geometry;**
CREATE TYPE line UNDER geometry;
CREATE TYPE polygon UNDER geometry;
- 4 **CREATE FUNCTION distance**
 (s1 geometry, s2 geometry)
 RETURNS BOOLEAN
 EXTERNAL NAME
 '/usr/lpp/db2se/gis!shapedist'
 ...
- CREATE FUNCTION within**
 (s1 geometry, s2 geometry)
 RETURNS BOOLEAN
 EXTERNAL NAME
 '/usr/lpp/db2se/gis!shapewithin'
 ...

Structured Types as Column Types

- 5 **CREATE TABLE customers (**
 cid INTEGER,
 name VARCHAR(20),
 income INTEGER,
 addr CHAR(20),
 loc **point**);
- CREATE TABLE stores (**
 sid INTEGER,
 name VARCHAR(20),
 addr CHAR(20),
 loc **point**,
 zone **polygon**);
- CREATE TABLE sales (**
 sid INTEGER,
 cid INTEGER,
 amount INTEGER);

CUSTOMERS

CID	NAME	INCOME	ADDR	LOC

STORES

SID	NAME	ADDR	LOC	ZONE

SALES

SID	CID	AMOUNT

Structured Types as Column Types

6

```
SELECT * FROM stores s, customers c
WHERE within(c.loc, s.zone)=1
      or distance(c.loc, s.loc)<100
ORDER BY s.name, c.name;
```

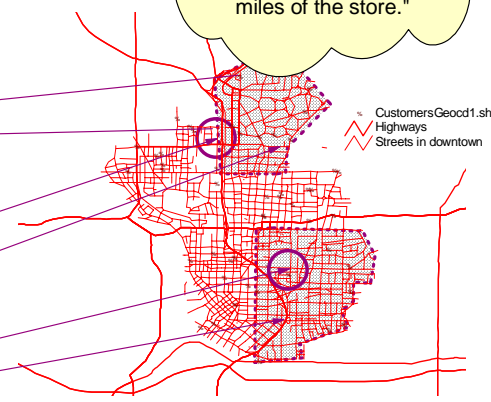
CUSTOMERS

CID	NAME	INCOME	ADDR	LOC

STORES

SID	NAME	ADDR	LOC	ZONE

"Tell me all the information I have about each customer who either lives within a stores' zone or within 100 miles of the store."



135

Structured Types as Row Types: Typed Tables

- Structured types can be used to define **typed tables**
 - Attributes of type become columns of table
 - Plus one column to define **REF value** for the row (object id)

```
CREATE TYPE real_estate AS
(owner          REF (person),
 price         money,
 rooms        INTEGER,
 size         DECIMAL(8,2),
 location     address,
 text_description text,
 front_view_image bitmap,
 document     doc) NOT FINAL
```

```
CREATE TABLE properties OF real_estate
(REF IS oid USER GENERATED)
```

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▼ Reference Types

- Structured types have a corresponding **reference type**
 - Can be used wherever other types can be used
- Representation
 - **User generated** (REF USING <predefined type>)
 - **System generated** (REF IS SYSTEM GENERATED)
 - **Derived** from a list of attributes (REF (<list of attributes>)
 - Default is system generated

```
CREATE TYPE real_estate AS (owner REF (person), ...)
NOT FINAL REF USING INTEGER
```

```
CREATE TYPE person AS (ssn INTEGER, name CHAR(30),...)
NOT FINAL REF (ssn)
```

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▼ Reference Types

- Reference values can be scoped
 - Only scoped ones can be dereferenced

```
CREATE TYPE person (ssn INTEGER, name ...) NOT FINAL
```

```
CREATE TYPE real_estate (owner REF (person), ...) NOT FINAL
```

```
CREATE TABLE people OF person ( ...)
```

```
CREATE TABLE properties OF real_estate
(owner WITH OPTIONS SCOPE people)
```

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▼ Reference Types

- References do not have the same semantics as referential constraints

```
CREATE TABLE T1
  (C1 REAL PRIMARY KEY, ...
```

```
CREATE TABLE T2
  (C2 DECIMAL (7,2) PRIMARY KEY, ...
```

```
CREATE TABLE T
  (C INTEGER, ...
  FOREIGN KEY (C) REFERENCES T1 (C1) NO ACTION,
  FOREIGN KEY (C) REFERENCES T2 (C2) NO ACTION)
```

- Referential constraints specify inclusion dependencies
 - It is unclear which table to access during dereferencing
- There is no notion of strong typing

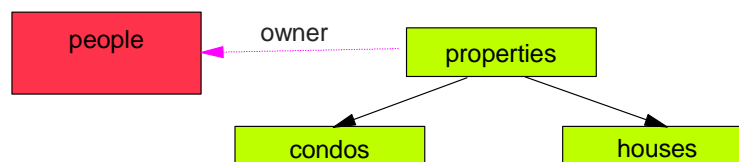
139

▼ Subtables: Table Hierarchies

- Typed tables can have subtables
 - Inherit columns, constraints, triggers, ... the supertable

```
CREATE TYPE person ... NOT FINAL
CREATE TYPE real_estate ... NOT FINAL
CREATE TYPE condo UNDER real_estate ... NOT FINAL
CREATE TYPE house UNDER real_estate ... NOT FINAL
```

```
CREATE TABLE people OF person ( ...)
CREATE TABLE properties OF real_estate
CREATE TABLE condos OF condo UNDER properties
CREATE TABLE houses OF house UNDER properties
```



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Substitutability

- Queries on table hierarchies range over the rows of every subtable

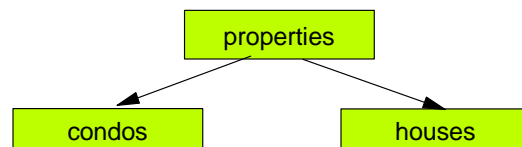
```
SELECT price, location.city, location.state FROM properties
WHERE contains (text_description, 'excellent school district')
```

- ▶ Returns properties, condos, and houses

- Queries on a subtable require SELECT privilege on that subtable

```
SELECT * FROM condos...
```

- Additional authorization required for queries that involve ONLY, or Deref on self-referencing column....



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Substitutability: Type Predicate and ONLY on Typed Tables

- **Type predicate** can be used to restrict selected rows

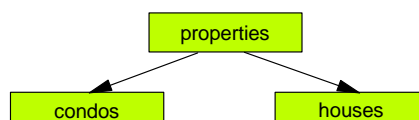
```
SELECT price, location.city, location.state
FROM properties
WHERE contains (text_description, 'excellent school district')
AND Deref (oid) IS OF (house)
```

- **ONLY** restricts selected rows to rows whose most specific type is the type of the typed table

```
SELECT price, location.city, location.state
FROM ONLY (properties)
WHERE contains (text_description, 'excellent school district')
```

- Queries on the target typed table that involve the ONLY modifier (or the Deref operation on its self-referencing column) require WITH HIERARCHY OPTION on that target table.

```
GRANT SELECT WITH HIERARCHY OPTION ON TABLE properties TO PUBLIC
```



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▼ Path Expressions - <dereference operator>

- Scoped references can be used in path expressions

```
SELECT prop.price, prop.owner->name FROM properties.prop
WHERE prop.owner->address.city = "Hollywood"
```

- Authorization checking follows SQL authorization model
 - user must have SELECT privilege on name and address

```
SELECT prop.price, (SELECT name FROM people p WHERE p.oid =
prop.owner)
FROM properties.prop
WHERE (SELECT p.address.city FROM people p WHERE p.oid = owner) =
"Hollywood"
```

```
SELECT prop.price, p.name
FROM properties prop LEFT JOIN people p ON (prop.owner = p.oid)
WHERE p.address.city = "Hollywood"
```

143

▼ Method Reference

- References can be used to invoked methods on the corresponding structured type

```
SELECT prop.price, prop.owner->income (1998)
FROM properties.prop
```

- Invocation of methods given a reference value require select privilege on the method for the target typed table

```
GRANT SELECT (METHOD income FOR person) ON TABLE
people TO PUBLIC
```

- Allows the table owner control who is authorized to invoked methods on the rows of his/her table

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Reference Resolution: Nesting

- References can be used to obtain the structured type value that is being referenced
 - Enables nesting of structured types

```
SELECT prop.price, Deref(prop.owner)
FROM properties.prop
```

- Reference resolution requires SELECT privilege WITH HIERARCHY OPTION on the target typed table

```
GRANT SELECT WITH HIERARCHY OPTION ON TABLE
people TO PUBLIC
```

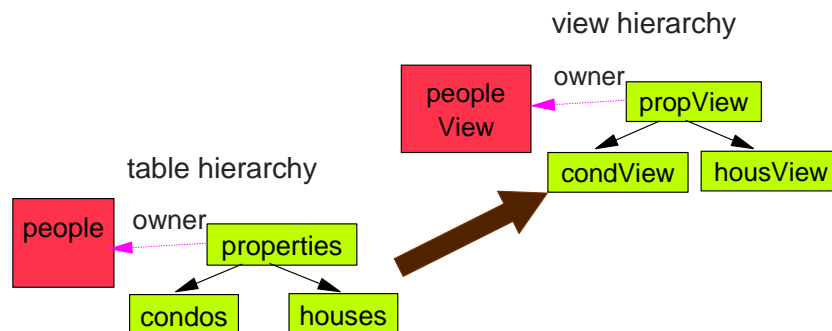
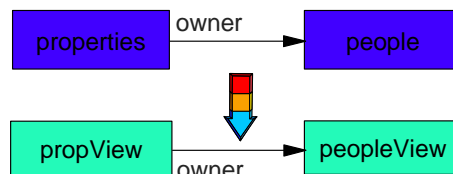
- DEREF nests rows from subtables, respecting value substitutability

145

Object Views

- Views have been extended to support

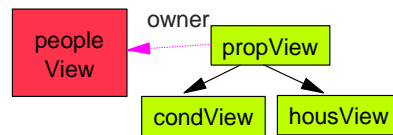
- Typed views
- View hierarchies
- References on base tables can be mapped to references on views



146

▼ Object Views: Example

```
CREATE TYPE propViewType AS
(owner REF (person),
location address) NOT FINAL
```



```
CREATE TYPE condViewType UNDER propViewType ...
CREATE TYPE housViewType UNDER propViewType ...
```

```
CREATE VIEW propView OF propViewType
REF IS propID USER GENERATED
(owner WITH OPTIONS SCOPE peopleView)
AS (SELECT owner, location FROM ONLY (properties) )
```

```
CREATE VIEW housView OF housViewType UNDER propView
AS (SELECT owner, location FROM ONLY (houses) )
```

```
CREATE VIEW condView OF condViewType UNDER propView
AS (SELECT owner, location FROM ONLY (condos) )
```

147

▼ Comparison of UDT Values

- CREATE ORDERING statement specifies
 - Which comparison operations are allowed for a user-defined type
 - How such comparisons are to be performed.

```
CREATE ORDERING FOR employee
EQUALS ONLY BY STATE;
```

```
CREATE ORDERING FOR complex
ORDER FULL BY RELATIVE
WITH FUNCTION complex_order (complex,complex);
```

- ORDERING form:
 - EQUALS ONLY
 - Only comparison operations allowed are =, <>
 - ORDER FULL
 - All comparison operations are allowed

148

▼ Comparison of UDT Values (cont.)

■ Ordering category

- ▶ STATE
 - An ordering function is implicitly created with two UDT parameters and returning Boolean
 - Compares pairwise the UDT attributes
- ▶ RELATIVE
 - User must specify an ordering function with two UDT parameters and returning INTEGER
 - 0 for equal, positive for >, negative for <
- ▶ MAP
 - User must specify an ordering function with one UDT parameter and returning a value of a predefined type
 - Comparisons are made based on the value of the predefined type

149

▼ Comparison of UDT Values (cont.)

■ Ordering category - Rules:

- ▶ STATE cannot be specified for distinct types.
- ▶ STATE and RELATIVE must be specified for the maximal supertype in a type hierarchy.
- ▶ MAP can be specified for more than one type in a type hierarchy, but all such types must specify MAP and all such types must have the same ordering form.
- ▶ STATE is allowed only for EQUALS ONLY.
- ▶ If ORDER FULL is specified, then RELATIVE or MAP must be specified.

150

▼ Comparison of UDT Values (cont.)

- Comparison type of a given type:
 - The nearest supertype for which a comparison was defined.
 - Comparison form, comparison category, and comparison function of a type are the ordering form, ordering category, ordering function of its comparison type.
- A value of type T1 is comparable to a value of type T2 if
 - T1 and T2 are in the same subtype family.
 - Comparison types of T1 and T2 both specify the same comparison category (i.e., STATE, RELATIVE, or MAP)
- Example
 - Person has subtypes: emp and mgr
 - Person has an ordering form, ordering category, and an ordering function
 - emp and mgr types have none
 - Person is the comparison type of emp and mgr
 - Two emp values, two mgr values, or a value of emp and a value of mgr can be compared.

151

▼ Comparison of UDT values (cont.)

- No comparison operations are allowed on values of structured types by default.
- All comparison operations are allowed on values of distinct types by default.
 - Based on the comparison of values of source type.
 - Whenever a distinct type is created, a CREATE ORDERING statement is implicitly executed (SDT is the source type).
 - The ordering function is the system-generated cast function

```
CREATE ORDERING FOR DT
ORDER FULL BY MAP WITH FUNCTION SDT(DT);
```

152

▼ Comparison of UDT values (cont.)

- A predicate of the form " $V1 = V2$ " is transformed into the following expression depending on the comparison category:
 - STATE
 - " $SF(V1, V2) = TRUE$ "
 - SF is the comparison function
 - MAP
 - " $MF1(V1) = MF2(V2)$ "
 - MF1 and MF2 are comparison functions
 - RELATIVE
 - " $RF(V1, V2) = 0$ "
 - RF is the comparison function

153

▼ Comparison of UDT Values (cont.)

- DROP ORDERING
 - Removes the ordering specification for an UDT

DROP ORDERING FOR employee RESTRICT;

- RESTRICT implies
 - There cannot be any
 - SQL- invoked routine
 - View
 - Constraint
 - Assertion
 - Trigger

that has a predicate involving employee values or values of subtypes thereof.

154

▼ User-defined Casts

- Allow a value of one type to be cast into a value of another type
 - At least one of the types in an user-defined cast must be a user-defined type or a reference type.

```
CREATE CAST(t1 AS t2) WITH FUNCTION foo (t1);
```

```
SELECT CAST(c1 AS t2) FROM TAB1;
```

- May optionally be tagged AS ASSIGNMENT

```
CREATE CAST(t1 AS t2) WITH FUNCTION foo (t1) AS ASSIGNMENT;
```

- Such casts get invoked implicitly during assignment operations.
- Above user-defined cast makes the following assignment legal:

```
DECLARE v1 t1, v2 t2;  
SET V2 = V1;
```

155

▼ User-defined Casts (cont.)

- DROP CAST
 - Removes the user-defined cast
 - Does not delete the corresponding function (only its cast flag is removed)

```
DROP CAST (T1 AS T2) RESTRICT;
```

- RESTRICT implies:

- There cannot be any
 - Routine
 - View
 - Constraint
 - Assertion
 - Trigger

that has

- An expression of the form "CAST(V1 AS T2)" where V1 is of type T1 or any subtype of T1;
- A DML statement that implicitly invokes the user-defined cast function.

156

▼ Cast Functions for Distinct Types

```
CREATE TYPE plan.meters
AS INTEGER FINAL
CAST (SOURCE AS DISTINCT) WITH meters
CAST (DISTINCT AS SOURCE) WITH integer
```

Implicit Cast Functions created:
plan.meters(integer) returns meters;
plan.integer(meters) returns integer;

Example Casting Expressions:

```
... SET RoomWidth =
    CAST (integerCol AS meters)
or
    meters(integerCol)
or
    meters(smallintCol)
```

- Automatically defines cast functions to and from the source type for a user-defined distinct type
 - Casts will also be allowed from any type that is promotable to the source type of the user-defined type (i.e., that has the source type in its type precedence list)
 - Casting from a SMALLINT to a UDT sourced on an integer is OK

157

▼ Cast Functions: Comparison Rules

```
SELECT * FROM RoomTable
WHERE RoomID = 'Bedroom';
ERROR
```

```
SELECT * FROM RoomTable
WHERE RoomID = roomtype('Bedroom');
```

or

```
SELECT * FROM RoomTable
WHERE char(RoomID) = 'Bedroom';
```

No Error Results

- Casts must be used to compare distinct type values with source-type values.
 - Constants are always considered to be source type values
 - You may cast from source type to UDT, or vice-versa

158

▼ Cast Functions: Assignment Rules

```
CREATE TYPE plan.meters
AS INTEGER FINAL
CAST (SOURCE AS DISTINCT) WITH meters
CAST (DISTINCT AS SOURCE) WITH integer
```

```
CREATE CAST ( plan.meters AS interger) WITH
integer AS ASSIGNMENT
```

```
CREATE CAST (integer AS plan.meters) WITH
meters) AS ASSIGNMENT
```

```
Select RoomLength, RoomWidth
INTO :int_hv1, :int_hv2
FROM RoomTable
```

```
Udate RoomTable
Set RoomLength = 10
```

No Error Results

- In general source-type values may not be assigned to user-defined type targets
- The strong typing associated with UDTs is relaxed for assignment operations, **IF AND ONLY IF**
 - A cast function between source and target type has been defined with the AS ASSIGNMENT clause

159

▼ Transforms

- Transforms are user-defined functions or methods that get invoked automatically whenever UDT values are exchanged between SQL and external programs.
- Each UDT is associated with a collection of transform groups; each transform group is associated with:
 - A from_sql function that maps a UDT value into a value of predefined type.
 - A to_sql function that maps a value of a predefined type into a UDT value.

160

▼ Transforms (cont.)

- CREATE TRANSFORM statement specifies a transform for a given UDT

```
CREATE TRANSFORM FOR point
  group1(FROM SQL WITH FUNCTION from_point1(point),
    TO SQL WITH FUNCTION to_point1(char(27))
  group2(FROM SQL WITH FUNCTION from_point2(point),
    TO SQL WITH FUNCTION to_point2(char(50)));
```

- A transform group with a given name can be specified for only one type within a type hierarchy.
- An implicit transform is created for every distinct type on its creation, based on its cast functions.

161

▼ Methods as Transform Functions

- Both from_sql and to_sql functions can be specified as methods:

```
CREATE TRANSFORM FOR point
  group1(FROM SQL WITH METHOD from_point1() FOR point,
    TO SQL WITH METHOD to_point1(char(27) FOR point)
  group2(FROM SQL WITH METHOD from_point2() FOR point,
    TO SQL WITH METHOD to_point2(char(50) FOR point);
```

- Both from_sql and to_sql methods can be overridden to define subtype-specific transform methods.

162

▼ Transforms in Embedded Programs

- An embedded program can specify transform groups for use during the execution of program:

```
TRANSFORM GROUP group1
```

```
TRANSFORM GROUP group2 FOR TYPE point
```

- A host variable whose data type is a UDT must specify a predefined type; must be same as the return type of from_sql function of the transform group specified for the UDT:

```
SQL TYPE IS point AS CHAR(50) pointvar
```

163

▼ Transforms in Embedded Programs (cont.)

- from_sql function or method is automatically invoked on the UDT value and the result is passed to the host variable:

```
EXEC SQL SELECT center INTO :pointvar FROM circles  
WHERE ...
```

- to_sql function or method is automatically invoked on the host variable value and the result is passed to SQL:

```
EXEC SQL UPDATE circles  
SET center = :pointvar  
WHERE ...
```

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▼ Transforms in External Routines

- An external routine can specify transform groups for use during the execution of routine:

```
CREATE FUNCTION foo(p1 point)
RETURNS INTEGER
EXTERNAL
TRANSFORM GROUP group1;
```

- The parameter in the external program corresponding to 'p1' must specify a host language type that corresponds to **CHAR(27)**.
- Transform functions for UDT parameters are picked during the creation of external routines; once selected, the transform functions are frozen.

165

▼ Transforms in External Routines (cont.)

- If there is no transform available for a UDT with a given group name, then a transform defined for one of its supertypes is picked.
- If transform functions are methods, the dynamic binding rules apply, i.e., if there is an overriding method available, that method is picked for execution.

166

▼ Transforms in Dynamic SQL

- SET TRANSFORM GROUP statement sets the transform group for one or more UDTs for use during execution of dynamic SQL statements:

```
SET DEFAULT TRANSFORM GROUP group1;
```

```
SET TRANSFORM GROUP FOR TYPE point group2;
```

- Two special registers are provided to inquire about the session defaults:

```
CURRENT_DEFAULT_TRANSFORM_GROUP;
```

```
CURRENT_TRANSFORM_GROUP_FOR_TYPE point;
```

167

▼ Dropping Transforms

- DROP TRANSFORM statement can be used to drop either a transform group or all transform groups attached to a UDT:

```
DROP TRANSFORM group1 FOR point RESTRICT;
```

```
DROP TRANSFORM ALL FOR point CASCADE;
```

- Dependencies between a transform group and the external routines that depend on that transform group are taken into account during dropping of transforms.

168

▼ Arrays

- The only collection type of SQL99
- Why arrays?
 - Tables with collection-valued columns
 - "repeating groups"
 - n1NF tables
 - Important building block for imperative code
 - Heavily used in Standard Type Libraries
 - SQL/MM Full-Text
 - SQL/MM Spatial

169

▼ Arrays (cont.)

- Array characteristics
 - Maximal length vs actual length (like CHARACTER VARYING)
 - Any element type admissible (except array types)
 - Substitutability applies at element level
 - "Arrays anywhere"
- Array operations
 - Element access by ordinal number
 - Cardinality
 - Comparison
 - Constructors
 - Assignment
 - Concatenation
 - CAST
 - Declarative selection facilities over arrays

170

▼ Arrays (cont.)

- Tables with array-valued columns

```
CREATE TABLE reports
(id          INTEGER,
 authors    VARCHAR(15) ARRAY[20],
 title      VARCHAR(100),
 abstract   FullText)
```

- Appropriate DML operations

```
INSERT INTO reports(id, authors, title)
VALUES (10, ARRAY ['Date', 'Darwen'], 'A Guide to the SQL
Standard')
```

171

▼ Arrays (cont.)

- Access to array elements
 - By ordinal position
 - Declarative (i.e. query) facility
 - Implicitly transforms array into table
 - Selection by element content and/or position
 - Unnesting
- Examples:

```
SELECT id, authors[1] AS name FROM reports
```

```
SELECT r.id, a.name
FROM reports AS r, UNNEST (r.authors) AS a (name)
```

172

▼ UDT and Array Locators

- Similar to large object locators.
- A host variable can be specified as a locator variable for a UDT or an array type:

```
SQL TYPE IS point AS LOCATOR pointvar;
```

```
SQL TYPE IS INTEGER ARRAY[10] AS LOCATOR avar;
```

- An unique implementation-dependent 4-octet integer locator value is generated and passed to the host variable:

```
EXEC SQL SELECT center INTO :pointvar
```

```
FROM circles WHERE ...
```

173

▼ UDT and Array Locators (cont.)

- When locators are used in assignment statements, the UDT or the array value corresponding to the given locator value is first found, and the result is then used in the assignment:

```
EXEC SQL UPDATE circles
```

```
SET center = :pointvar
```

```
WHERE ...
```

- A parameter of an external routine can be specified as locator parameter if its data type is either a UDT or an array type, or the returns type of an external function can specify AS LOCATOR if it is either a UDT or an array type:

```
CREATE FUNCTION foo(p1 emp AS LOCATOR)
```

```
RETURNS emp AS LOCATOR
```

```
EXTERNAL ...
```

174

▼ UDT and Array Locators (cont.)

- When the routine is invoked, an unique implementation-dependent 4-octet integer locator value is generated for each input locator parameter and passed as the argument value.
- After the routine finishes execution, for each output locator parameter or function result, the UDT or the array value corresponding to the locator value is first found, and the result is then returned to the caller.

175

▼ Examples

- Some examples used throughout this presentation are based on the following schema:

```
CREATE TABLE people(  
  lname CHAR(20),  
  fname CHAR(20),  
  nick CHAR(20)  
  UNIQUE (lname, fname)  
);
```

```
SQL>SELECT * FROM hobbies;
```

```
CREATE TABLE hobbies  
(last CHAR(20),  
 first CHAR(20),  
 hobby CHAR(15)  
);
```

<u>LAST</u>	<u>FIRST</u>	<u>HOBBY</u>
Holland	William	travel
Smith	Roberta	sailing
.	.	.
.	.	.
.	.	.
.	.	.

176

▼ Constraints

- Constraints have names
- Checking of constraints can be
 - ▶ Performed at the end of SQL statement (SQL/89)
 - ▶ Deferred until the end of transaction
- Constraints and assertions can be defined as
 - ▶ Deferrable or not deferrable
 - ▶ Initially deferred or initially immediate

```
ALTER TABLE people
  ADD CONSTRAINT pk UNIQUE (lname, fname)
  DEFERRABLE
  INITIALLY IMMEDIATE;
SET CONSTRAINTS pk DEFERRED;
```

...

```
COMMIT;
```

- At commit time if any constraint is not satisfied, then
 - ▶ An exception is raised
 - ▶ The transaction is rolled back

177

▼ Constraints (cont.)

- SQL92 has defined several kinds of constraints:
 - ▶ Primary key specification
 - ▶ NOT NULL
 - ▶ UNIQUE constraints
 - ▶ Check constraints - defined at table level
 - ▶ Assertions - defined at schema level
 - ▶ Referential Constraints

```
CREATE TABLE EMPLOYEES
(ID          INTEGER          PRIMARY KEY,
NAME        VARCHAR (30)     NOT NULL,
DEPT        SMALLINT         REFERENCES DEPTMENTS,
JOB         CHAR (5)         CHECK (JOB IN ('SALES', 'MGR', 'CLERK')) )
```

178

▼ UNIQUE Constraint

- Columns of a UNIQUE constraint can be nullable (do not require NOT NULL)
- A row with a null value in a column of a UNIQUE constraint is not a duplicate of any other row

```
ALTER TABLE hobbies  
ADD CONSTRAINT  
UNIQUE (last, first, hobby);
```

Hobbies

LAST	FIRST	HOBBY
Holland	William	fishing
Holland	William	NULL
Holland	William	NULL

179

▼ Check Constraints

- What they are:
 - ▶ Constraints over the values of columns in tables
 - ▶ Associated with base table or individual columns
 - ▶ Defined and/or altered at any time
 - ▶ Subqueries are allowed in check constraints
- Uses:
 - ▶ Define a range of allowable values:
 - *The values of department number must lie in the range 10 to 100.*
 - ▶ Define a list of possible values:
 - *The job of an employee can only be sales, manager, or clerk.*
 - ▶ Keep interdependencies:
 - *Every employee that has been with the company more than 8 years must make more than \$40,500.*

```
CREATE TABLE EMPLOYEES  
(ID INTEGER NOT NULL,  
NAME VARCHAR (30),  
HIREDATE DATE,  
DEPT SMALLINT CHECK (DEPT BETWEEN 10 AND 100),  
JOB CHAR (5) CHECK (JOB IN ('SALES', 'MGR', 'CLERK')),  
SALARY US_DOLLAR CHECK (SALARY > US_DOLLAR (1000))  
...  
CONSTRAINT YEARSAL CHECK (YEAR (HIREDATE) > 1986 OR  
SALARY > US_DOLLAR (40500)))
```

180

▼ Assertions

- Constraints that can apply to an entire table or to multiple tables

```
CREATE ASSERTION max_employee
  CHECK ( ( SELECT COUNT (*)
            FROM employee ) < 250000 );
```

```
CREATE ASSERTION max_sal_expense
  CHECK ( ( SELECT SUM ( salary )
            FROM employee )
          <
          .8*( SELECT SUM ( budget )
              FROM dept) );
```

181

▼ Referential Constraints

- Three flavors of referential constraints for handling nulls
 - "vanilla" (nulls don't match, since equality requirement not satisfied)
 - PARTIAL MATCH
 - FULL MATCH

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▼ Referential Constraints, Vanilla

```
CREATE TABLE hobbies
(...
  FOREIGN KEY (last, first)
  REFERENCES people (lname, fname));
```

People

LNAME	FNAME	NICK
Holland	William	Bill
Zysko	William	Willy

referenced

Hobbies

LAST	FIRST	HOBBY
Holland	William	Fishing
Zysko	William	Dancing
Smith	(null)	Painting
(null)	William	Sailing
(null)	(null)	Garden

matching rows

referencing

- Columns of referenced table must be defined in a unique constraint
- For each row of the referenced table, the matching rows in the referencing table are those for which corresponding columns are equal
- Null value in any column of foreign key means that row will not be checked (note: such a row is not a matching row)

183

▼ Ref Constraints: MATCH PARTIAL

```
ALTER TABLE hobbies
  ADD FOREIGN KEY (last, first)
  REFERENCES people (lname, fname)
  MATCH PARTIAL);
```

People

LNAME	FNAME	NICK
Holland	William	Bill
Zysko	William	Willy

referenced

Hobbies

LAST	FIRST	HOBBY
Holland	William	Fishing
Zysko	William	Dancing
Smith	(null)	Painting
(null)	William	Sailing
(null)	(null)	Garden

matching rows

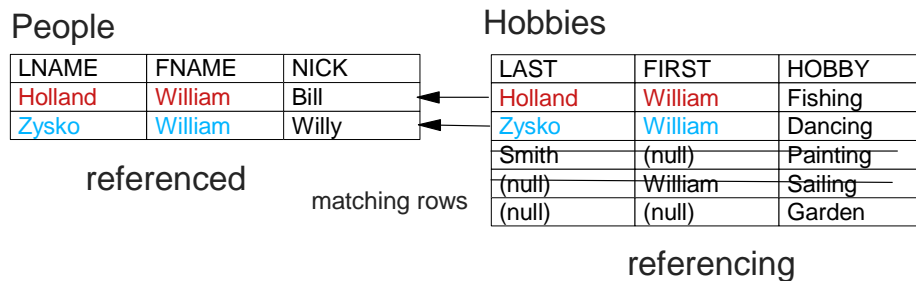
referencing

- All of the values of the FK that are not null must match corresponding columns of a row in the referenced table
- Matching rows for a given row in the referenced table have at least one non-null key column and are equal to the corresponding column in the referenced table
- Unique matching rows for a given row in the referenced table are those that are matching rows only to that row of the referenced table

184

▼ Ref Constraints: MATCH FULL

```
ALTER TABLE hobbies
  ADD FOREIGN KEY (last, first)
  REFERENCES people (lname, fname)
  MATCH FULL);
```



- Rows of the referencing table must contain either
 - All null values or all non-null values for the columns of the foreign key
- Matching rows are the same as when the match type is not specified
- MATCH FULL or (the default) MATCH SIMPLE differ with regard to admissible non-matching

185

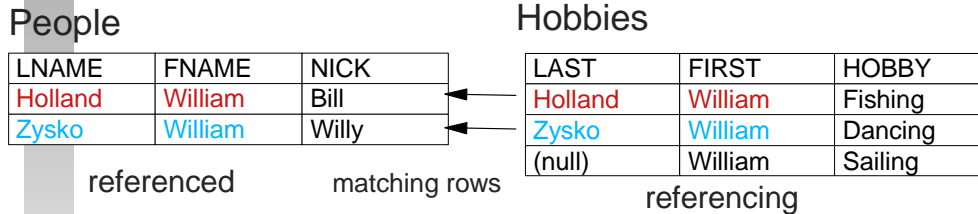
▼ Referential Constraints: Actions

- Define actions on update or delete of rows in the referenced table
 - NO ACTION
 - RESTRICT
 - CASCADE
 - SET NULL
 - SET DEFAULT
- Rules must be deterministic
 - Where the result would be order-dependent an exception will be raised
- Checked after the execution of an SQL statement
- Matching rows are determined before referential actions take place
- A matching row relationship may be dropped during execution of referential actions (except for restrict)
- New relationships will not be recognized until after the action has completed (PARTIAL MATCH only)

186

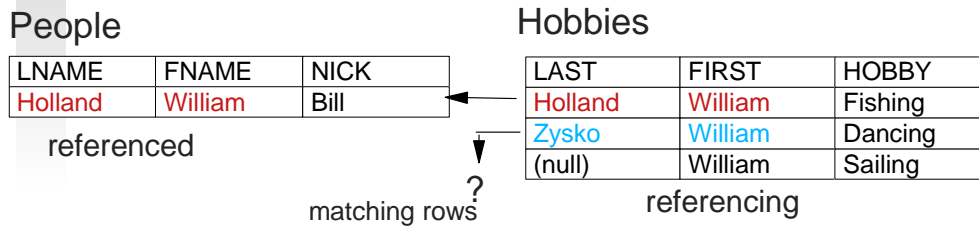
Ref Constraints: NO ACTION

```
ALTER TABLE hobbies
  ADD FOREIGN KEY (last, first)
  REFERENCES people (lname, fname)
  ON DELETE NO ACTION);
```



```
DELETE FROM people
WHERE lname='Zysko';
```

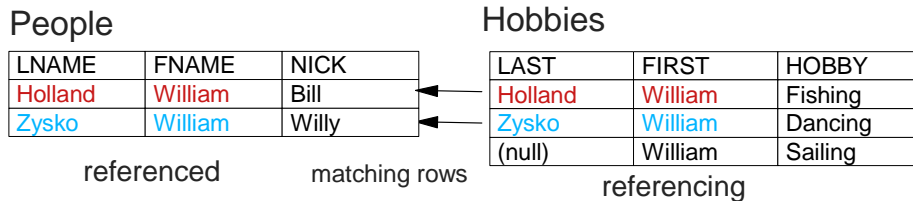
⚡ Exception: integrity constraint violation



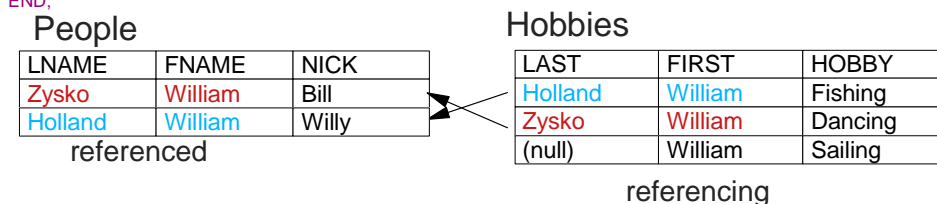
187

Ref Constraints: ON UPDATE NO ACTION

```
ALTER TABLE hobbies
  ADD FOREIGN KEY (last, first)
  REFERENCES people (lname, fname)
  ON UPDATE NO ACTION);
```



```
UPDATE people SET lname=CASE lname
  WHEN 'Holland' THEN 'Zysko'
  WHEN 'Zysko' THEN 'Holland'
END;
```



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Ref Constraints: ON UPDATE RESTRICT

```
ALTER TABLE hobbies
  ADD FOREIGN KEY (last, first)
  REFERENCES people (lname, fname)
  ON UPDATE RESTRICT;
```

People

LNAME	FNAME	NICK
Holland	William	Bill
Zysko	William	Willy

referenced

matching rows

Hobbies

LAST	FIRST	HOBBY
Holland	William	Fishing
Zysko	William	Dancing
(null)	William	Sailing

referencing

```
UPDATE people SET lname=CASE lname
  WHEN 'Holland' THEN 'Zysko'
  WHEN 'Zysko' THEN 'Holland'
END;
```



Exception: integrity constraint violation

People

LNAME	FNAME	NICK
Zysko	William	Bill
Holland	William	Willy

referenced

Hobbies

LAST	FIRST	HOBBY
Holland	William	Fishing
Zysko	William	Dancing
(null)	William	Sailing

referencing

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Ref Constraints: ON DELETE CASCADE

```
ALTER TABLE hobbies
  ADD FOREIGN KEY (last, first)
  REFERENCES people (lname, fname)
  ON DELETE CASCADE;
```

People

LNAME	FNAME	NICK
Holland	William	Bill
Zysko	William	Willy

referenced

matching rows

Hobbies

LAST	FIRST	HOBBY
Holland	William	Fishing
Zysko	William	Dancing
(null)	William	Sailing

referencing

```
DELETE FROM people
  WHERE lname='Zysko';
```

People

LNAME	FNAME	NICK
Holland	William	Bill

referenced

matching rows

Hobbies

LAST	FIRST	HOBBY
Holland	William	Fishing
(null)	William	Sailing

referencing

190

Ref Constraints: ON UPDATE SET NULL

```
ALTER TABLE hobbies
ADD FOREIGN KEY (last, first)
REFERENCES people (lname, fname)
ON UPDATE SET NULL);
```

People			Hobbies		
LNAME	FNAME	NICK	LAST	FIRST	HOBBY
Holland	William	Bill	Holland	William	Fishing
Zysko	William	Willy	Zysko	William	Dancing
			(null)	William	Sailing

referenced matching rows referencing

```
UPDATE people
SET fname='John'
WHERE lname='Holland';
```

People			Hobbies		
LNAME	FNAME	NICK	LAST	FIRST	HOBBY
Holland	John	Bill	(null)	(null)	Fishing
Zysko	William	Willy	Zysko	William	Dancing
			(null)	William	Sailing

referenced matching rows referencing

191

Ref Constraints: MATCH PARTIAL ON UPDATE CASCADE

```
ALTER TABLE hobbies
ADD FOREIGN KEY (last, first)
REFERENCES people (lname, fname)
MATCH PARTIAL ON UPDATE CASCADE);
```

People			Hobbies		
LNAME	FNAME	NICK	LAST	FIRST	HOBBY
Holland	William	Bill	Holland	William	Fishing
Zysko	William	Willy	Zysko	William	Dancing
			(null)	William	Sailing

referenced matching rows referencing

```
UPDATE people
SET fname='John'
WHERE lname='Holland';
```

People			Hobbies		
LNAME	FNAME	NICK	LAST	FIRST	HOBBY
Holland	John	Bill	Holland	John	Fishing
Zysko	William	Willy	Zysko	William	Dancing
			(null)	William	Sailing

referenced matching rows referencing

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Ref Constraints: MATCH PARTIAL ON UPDATE CASCADE

```
ALTER TABLE hobbies
  ADD FOREIGN KEY (last, first)
  REFERENCES people (lname, fname)
  MATCH PARTIAL ON UPDATE CASCADE);
```

People			Hobbies		
LNAME	FNAME	NICK	LAST	FIRST	HOBBY
Holland	William	Bill	Holland	William	Fishing
Zysko	William	Willy	Zysko	William	Dancing
			(null)	William	Sailing

referenced matching rows referencing

```
UPDATE people
  SET fname=nick'
  WHERE fname='William';
```

⚡ Exception: triggered data change operation

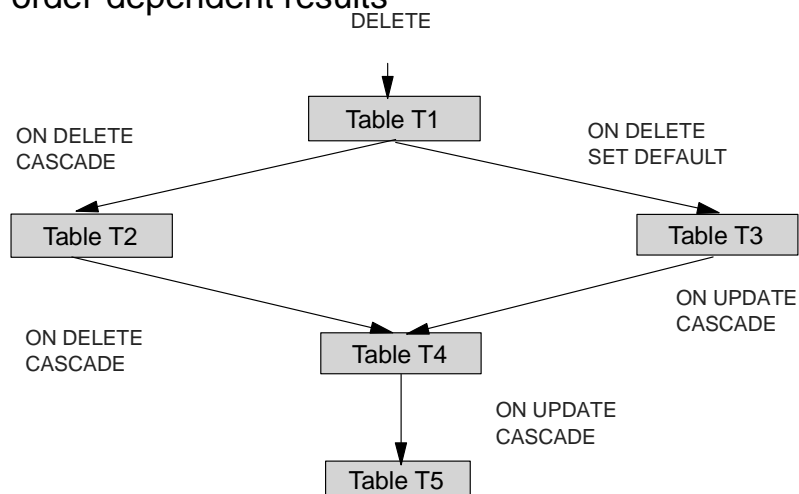
People			Hobbies		
LNAME	FNAME	NICK	LAST	FIRST	HOBBY
Holland	Bill	Bill	Holland	Bill	Fishing
Zysko	Willy	Willy	Zysko	Willy	Dancing
			(null)	???	Sailing

referenced matching rows referencing

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Referential Constraints

- More than one action can be applied to a single row
- Both actions are performed to avoid order-dependent results



194

▼ Ref Integrity between Comparable Types

- Foreign key does not have to be exact type as primary key, just **comparable**. For example:
 - ▶ VARCHAR to CHAR
 - ▶ INTEGER to DECIMAL to REAL
 - ▶ Supertype to subtype (e.g., person to manager)

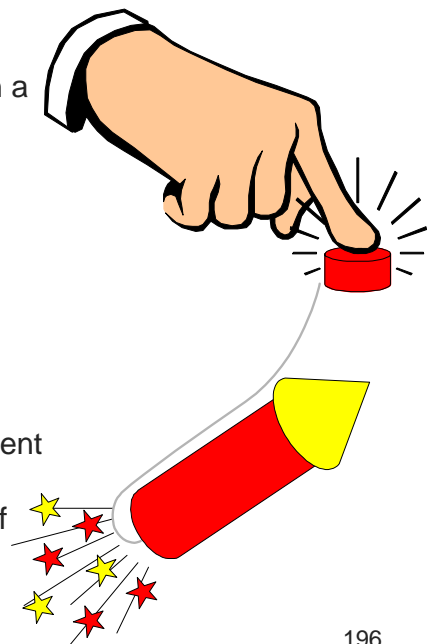
```
CREATE TABLE people
(lname VARCHAR(40),
fname VARCHAR(30),
nick CHAR (15),
PRIMARY KEY(lname,fname)
...
```

```
CREATE TABLE hobbies
(last CHAR(30)
first CHAR(15)
hobby VARCHAR (50)
FOREIGN KEY (last, first)
REFERENCES people (lname, fname));
```

195

▼ Triggers Overview

- Triggers provide automatic execution of a set of SQL statements when a specific data change operation (UPDATE, INSERT, DELETE) occurs
- Bring application logic into the database
- Transform a passive to active DBMS
- Benefits of triggers include
 - Code reuse
 - Faster application development
 - Easier Maintenance
 - Guaranteed enforcements of business rules



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Common Uses for Triggers

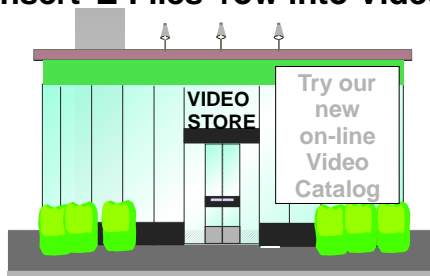
- Enforce "transitional" business rules
- Validate input data
- Generate new values for inserted / updated rows
- Cross-reference other tables
- Maintain audit, summary or mirror data in other tables
- Support "alerts"
 - E-mail notification
 - Initiate external actions



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Trigger Flow

Insert 'Z-Files' row into Video_Table



Category_Table		
Category	CatNo	Cat_Total
Adventure	A07	1
Comedy	C28	1
Romance	R67	1
Science Fiction	S31	2

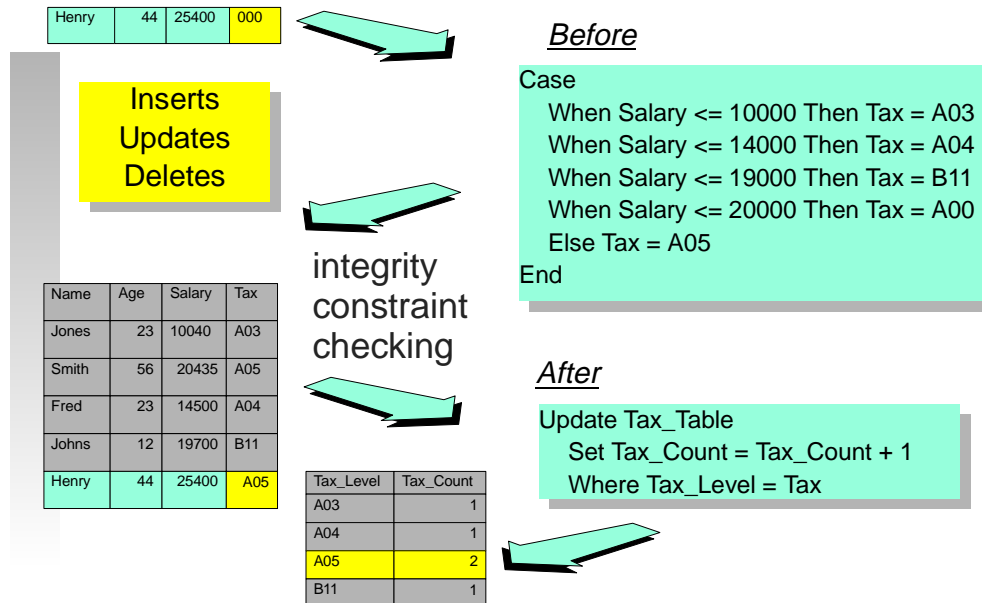
Video_Table		
Title	Code	Price
Toy Glory	C28	14.95
Star Trak	S31	14.95
Indiana Bones	A07	15.95
Titanic	R67	19.95
Z-Files	S31	25.95

AFTER TRIGGER

Update Category_Table
 Set Cat_Total = Cat_Total + 1
 Where CatNo = Code

198

▼ Trigger: complete flow



199

▼ Trigger Characteristics

```

CREATE TRIGGER Payroll
  AFTER UPDATE OF salary ON Paytable
  FOR EACH STATEMENT
  INSERT INTO PAYROLL_LOG ...;
  
```



Triggering Table: Table on which the trigger is defined

Triggering Event:

An SQL Data Change Operation (INSERT,DELETE,UPDATE)
UPDATE can be qualified by column

ON the triggering table

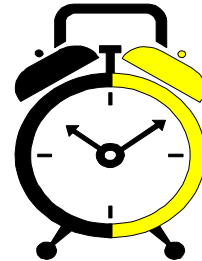
Trigger Activation Time: BEFORE or AFTER

Trigger Granularity: FOR EACH ROW or FOR EACH STATEMENT

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▼ Trigger Activation Time

```
CREATE TRIGGER update_balance
BEFORE INSERT ON account_history /* event */
REFERENCING NEW AS ta
FOR EACH ROW
WHEN (ta.TA_type = 'W') /* condition */
UPDATE accounts /* action */
SET balance = balance - ta.amount
WHERE account_# = ta.account_#;
```



BEFORE

Evaluated entirely before triggering event

Can be considered an extension of the constraint system

Prevent invalid update operations

Useful for conditioning of input data

Validate or directly modify input values

SET allows you to modify values of affected rows

Only allowed in BEFORE triggers

201

▼ Trigger Activation Time

```
CREATE TRIGGER take_action
AFTER UPDATE OF balance ON accounts
REFERENCING OLD AS old_value
NEW AS new_value
FOR EACH ROW
WHEN (new_value.balance < 0)
IF account_type = 'VIP' THEN INSERT INTO send_letters ...
ELSE INSERT INTO blocked_accounts ...;
```



AFTER

Evaluated entirely after the triggering event

Can be considered an encapsulation of application logic that normally would be performed by the updating application

Perform audit trail logging or maintain summary data

Perform actions outside the database such as writing to an external dataset or sending an e-mail message

202

▼ Trigger Granularity

```
CREATE TRIGGER AddOrder
BEFORE INSERT ON Order
REFERENCING NEW AS NewRow
FOR EACH ROW
SET NewRow.Date = CURRENT_DATE;
```

```
CREATE TRIGGER Purchase
AFTER INSERT ON Order
FOR EACH STATEMENT
CALL E-MAIL_CONFIRMATION;
```

Granularity controls how many times the trigger is executed
FOR EACH ROW: Executed once for each row modified by the triggering event

Referred to as a row trigger or a row-level trigger

FOR EACH STATEMENT: Executed once each time the triggering SQL statement is issued

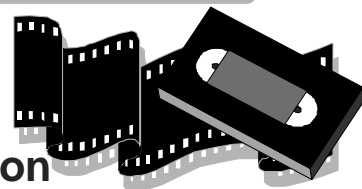
Referred to as a statement trigger or a statement-level trigger

203

▼ Triggered Action Condition

```
CREATE TRIGGER ReOrder
AFTER UPDATE OF InStock ON Video_Table
REFERENCING NEW AS N
FOR EACH ROW
WHEN (N.InStock < 0.10 * N.MaxStock)
CALL ORDER_VIDEO(N.MaxStock - N.InStock, N.Video_Num);
```

- Triggered action condition is optional
- Condition can be any SQL condition (involving complex queries)
 - ▶ In the form of a WHEN clause (similar syntax to a WHERE clause)
 - ▶ Trigger will not fire if WHEN clause not satisfied



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▼ Triggered SQL Statement



```
CREATE TRIGGER AddVideo
AFTER INSERT ON Video_Table
REFERENCING NEW AS Newrow
FOR EACH ROW
BEGIN ATOMIC
  UPDATE Item_Table SET Item_cnt = Item_cnt + 1
  WHERE ItemNo = Newrow.ItemNo;
  CALL E-MAIL_CUSTOMERS;
END;
```

- Triggered SQL statements
 - ▶ One or more SQL statements that are executed if WHEN clause evaluates true
 - ▶ Multiple statements are enclosed in BEGIN ATOMIC...END
 - ▶ Can include stored procedure call and functions

205

▼ Transition Variables



```
CREATE TRIGGER Increase
BEFORE UPDATE OF Salary_Table ON Employee
REFERENCING OLD AS Oldrow
              NEW AS Newrow
FOR EACH ROW
WHEN (Newrow.Salary > Oldrow.Salary * 1.20)
SET Newrow.Salary = Oldrow.Salary * 1.20;
```

- Transition Variables:
 - ▶ Contain column values of row affected by triggering operation
 - ▶ REFERENCING clause enables a correlation name to be assigned to the before and after states of the row
 - **OLD AS Oldrow**: Value of row before triggering SQL operation
 - **NEW AS Newrow**: Value of row after triggering SQL operation

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▼ Transition Tables

```
CREATE TRIGGER Large_Order
AFTER INSERT ON Invoice
REFERENCING NEW_TABLE AS N_Table
FOR EACH STATEMENT
SELECT
    LARGE_ORDER_ALERT(Cust_No, Total_Price, Delivery_Date)
    FROM N_Table WHERE Total_Price > 10000
```

■ Transition Tables

- ▶ Contains entire set of rows affected by triggering operation
- ▶ Apply aggregations over the set of affected rows (MAX, MIN, AVG)
- ▶ REFERENCING clause specifies a table identifier
 - **OLD_TABLE AS identifier**: Table of BEFORE values
 - **NEW_TABLE AS identifier**: Table of AFTER values
- ▶ Only valid for AFTER triggers

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▼ Valid Trigger Characteristic Combinations

Granularity	Activation Time	Triggering Operation	Transition Variables Allowed	Transition Tables Allowed
ROW	BEFORE	INSERT	NEW	NONE
		UPDATE	OLD, NEW	
		DELETE	OLD	
	AFTER	INSERT	NEW	NEW_TABLE
		UPDATE	OLD, NEW	OLD_TABLE, NEW_TABLE
		DELETE	OLD	OLD_TABLE
STATEMENT	BEFORE	INSERT	NONE	NONE
		UPDATE		
		DELETE		
	AFTER	INSERT	NONE	NEW_TABLE
		UPDATE		OLD_TABLE, NEW_TABLE
		DELETE		OLD_TABLE

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Statements Allowed as Triggered SQL

- Allowed in BEFORE triggers:
 - All DML statements except INSERT, UPDATE, and DELETE statements, invocations of routines that possibly modify SQL-data, connection and transaction statements
 - SET new transition variable
- Allowed in AFTER triggers:
 - All DML statements, except connection and transaction statements

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Invoking UDFs and Stored Procedures

- Triggers can only perform SQL operations
- Ability to invoke stored procedures and user-defined functions expands types of possible triggered actions to include:
 - Conditional logic and looping
 - Initiation of external actions
 - Access to non-database resources

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▼ Raising Error Conditions



```
CREATE TRIGGER Creditck
AFTER UPDATE OF Balance ON Customer
REFERENCING NEW AS Newrow
FOR EACH ROW
WHEN (Newrow.Balance > Newrow.CreditLimit)
    SIGNAL SQLSTATE '75001' ('Credit Limit Exceeded -
    Shred Card');
```

- Triggers can be used for stopping invalid updates and for detecting other invalid conditions.
 - ▶ SIGNAL SQLSTATE - New SQL statement that halts processing and returns the requested SQLSTATE and message to the application.
Format:
**SIGNAL SQLSTATE sqlstate-string-constant
(diagnostic-string-constant)**
 - Only valid in triggered actions

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▼ Triggers - Misc.

Trigger cascading

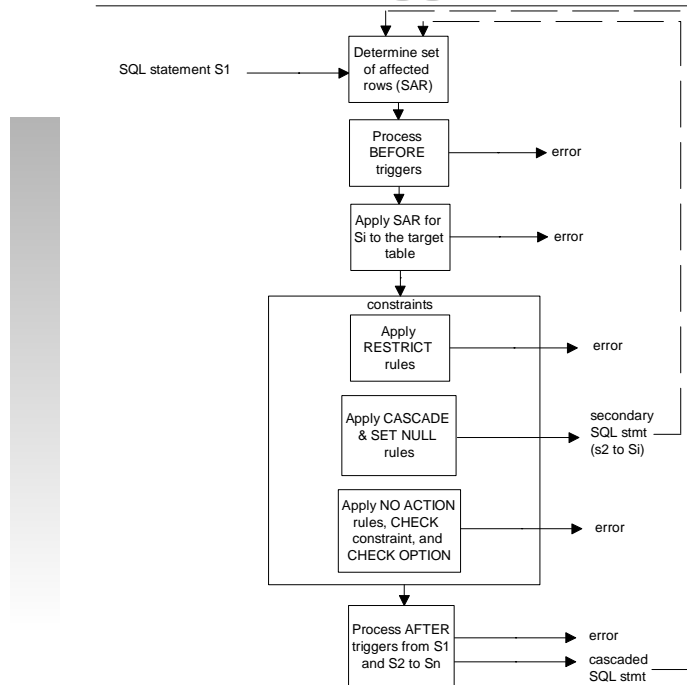
- ▶ Triggers can cause other triggers to fire

Interaction with RI and other constraints

- ▶ Trigger actions can cause checking constraints
- ▶ Trigger actions can cause RI checks to be performed
- ▶ RI actions can activate triggers
- ▶ Several triggers per event/activation time
 - ▶ Ordering: ascending order of creation

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SQL3's Trigger Execution Model



213

Predicates

- From SQL/89
 - ▶ Comparison (=, <, >, <=, >=, <>)
 - ▶ value1 BETWEEN value2 AND value3
 - ▶ value1 IN subquery or (value-list)
 - ▶ column LIKE pattern ESCAPE char
 - ▶ column IS NULL
 - ▶ value comp-op ALL or ANY subquery
 - ▶ EXISTS subquery
- Added in SQL/92
 - ▶ row-value IS NULL
 - ▶ row-value comp-op ALL or ANY or SOME subquery
 - ▶ UNIQUE subquery
 - ▶ row-value MATCH options subquery
 - ▶ row-value1 OVERLAPS row-value2
 - ▶ pred IS TRUE or FALSE or UNKNOWN

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▼ New and Extended Predicates

- Extensions
 - BETWEEN predicate (syntactic sugar)
 - LIKE predicate (BLOB support)
 - Matching rows: SIMPLE match (syntactic salt)
- New predicates
 - DISTINCT predicate (no SIMPLE match)
 - SIMILAR predicate (GREG facilities)
 - Type predicate (tests dynamic types)

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▼ Predicate Extensions: BETWEEN

- **A BETWEEN B AND C**
B A C
- SQL92: Implicit assumption: $B \leq C$
- SQL99: new syntax, same behavior
A BETWEEN B AND C
same as
A BETWEEN ASYMMETRIC B AND C
- New in SQL99: Limits may be specified in any order:
A BETWEEN SYMMETRIC C AND B

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▼ Predicate Extensions: MATCH SIMPLE

- No new functionality (over SQL92)
- Better syntactic visibility for testing whether a row has a matching row in the result of a subquery
- Example:

C.ForeignKey MATCH SIMPLE (VALUES (P.PrimaryKey))

- ▶ Match, if operands NOT DISTINCT
- Corresponding MATCH option in foreign key definition

217

▼ New in SQL99: DISTINCT Predicate

- Tests distinctness of two rows
- 2 rows DISTINCT, if at least two corresponding fields distinct
 - ▶ Scalar fields are not distinct if:
 - One of them NULL or
 - Both equal
 - ▶ Row-valued fields: recurse
 - ▶ Array-valued fields: Analogously to rows
- Note: NOT DISTINCT does not necessarily imply equality

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▼ New in SQL99: SIMILAR Predicate

- Specify character string similarity by regular expressions
- Well-known UNIX feature (e.g. GREP)
- Search patterns allow for
 - Masking symbols (% , _ (like LIKE))
 - Repetition (* , +)
 - Enumeration (e.g. [,; !?])
 - Negation (e.g. [^02468])
- Example:
`WHERE T.Name SIMILAR TO 'St[.]*[aA]nford'`

219

▼ New in SQL99: Type predicate

- Allows determination of dynamic type
- Purpose
 - Allows row selection by specific subtypes (e.g. only with EURO in MONEY column)
 - Allows to prune off certain subtypes (e.g. French Francs)
- **Example:** Find items from table *real_estate_info* table that are priced in EURO (but not in any of its substitutes, e.g. Dutch guilders):
`SELECT * FROM real_estate_info
WHERE Price IS OF ONLY (EURO)`

220

▼ SET Operators

- From SQL/89
 - UNION, but only in cursor declarations
- Added in SQL/92
 - UNION usable “everywhere”
 - INTERSECT
 - EXCEPT (“difference”)
 - CORRESPONDING options

Find all people that do not have hobbies:

```
(SELECT lname, fname
FROM people)
EXCEPT
(SELECT last, first
FROM hobbies)
```

221

▼ DML Orthogonality

- Constructors exist for rows and tables

```
VALUES ('Holland', 'John')
VALUES ( ('Bartz', 'Mary'), ('Lindsay', 'Bob') )
```

- Special 1-row SELECTs:
VALUES (CURRENT TIME) INTO :hv

- Multirow inserts:
INSERT INTO PROVINCE
VALUES (('BC', 'British Columbia'),
('AB', 'Alberta'), ...
('NF', 'Newfoundland'))

- In-memory (transient) “tables”:
SELECT NATION, POPULATION
FROM NATIONS
UNION ALL
VALUES ('Quebec', 6000000),
('California', 24000000)

222

▼ DML Orthogonality (cont.)

- Predicates operate on rows, rather than scalars

```
(SELECT lname, fname FROM people WHERE ...) -- row subquery
```

```
=
```

```
(SELECT last, first FROM hobbies WHERE ...) -- row subquery
```

223

▼ DML Orthogonality (cont.)

- Subquery can be used wherever expressions are allowed
 - Implicit conversion from row with single column to scalar value (problem)

- On right hand side of expressions:

```
SELECT *  
FROM people  
WHERE lname = (SELECT last  
FROM hobbies  
WHERE hobby = 'travel')
```

- UPDATE based on another table:

```
UPDATE employee  
SET salary = (SELECT MAX(salary)  
FROM mgr_employee)  
WHERE employee.name = 'Doe'
```

- In the SELECT list:

```
SELECT AVG(salary),  
  (SELECT AVG(salary) FROM mgr_employee),  
  (SELECT AVG(salary) FROM temp_employee)  
FROM employee  
SELECT last, first, ( SELECT description  
FROM hobby_description h  
WHERE h.name = hobbies.hobby)  
FROM hobbies  
WHERE ...
```

224

▼ CAST Specification

CAST (<expression> AS <data type>)

- Converts a value of one data type into a value of another data type

CAST (salary AS CHAR (10))

CAST (:string AS INTEGER)

CAST (mtg_date AS CHAR (14))

- Not all combinations of source and target data type are valid
- When particular values cannot be represented in the target data type an exception is raised

CAST ('1992-FEBRUARY-29' AS DATE)

- Uses

- Force proper data types for UNION and similar operators
- Assignment to host variables (e.g., DATE)
- Produce printable results

225

▼ CASE Expression

- If/then/else logic in SQL
Powerful way of embedding logic in SELECT and WHERE clauses

- Translation of encoded values

```
SELECT abbreviation, CASE
  WHEN abbreviation = 'CA' THEN 'California'
  WHEN abbreviation = 'SD' THEN 'South Dakota'
  WHEN ...
  ELSE 'Unknown'
END
FROM states
WHERE ...
```

- Used to “implement” COALESCE
SELECT COALESCE (nick, first, last, 'Unknown')
FROM people

- Protection against exceptions

```
SELECT emp_name, deptno
FROM employee
WHERE ( CASE bonus + commission
        WHEN 0 THEN NULL
        ELSE salary / (bonus+commission) )
> 10
```

226

Joined Tables

- SQL-89 provides only
 - Cross products
 - Inner joins

```
SELECT lname, nick, hobby
FROM people, hobbies
WHERE people.fname = hobbies.first
AND people.lname = hobbies.last
```
- SQL-92 adds 3 types of joined table
 - Cross join (new syntax)
 - Inner join (new syntax)
 - Union join
 - Outer join - left, right, and full
- Variations
 - Named columns join
 - Natural join
 - Cross join
 - "Old style" join without WHERE clause

```
SELECT *          SELECT *
FROM ( people    FROM people, hobbies
  CROSS JOIN
  hobbies) AS result
```

227

Outer Join

- Left, Right, and Full
- May be nested
- Joins two tables in such a way that includes rows from one table that have no match in the other

People

LNAME	FNAME	NICK
Adams	John	(null)
Holland	William	Bill
Zysko	William	Willy

Hobbies

LAST	FIRST	HOBBY
Holland	William	Fishing
Zysko	William	Dancing
(null)	William	Sailing

Show people who have no hobbies

```
SELECT lname, fname, hobby
FROM people
LEFT OUTER JOIN hobbies
ON lname=last;
```

```
lname    fname    hobby
Adams    John     (null)
Holland  William  Fishing
Zysko    William  Dancing
```

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Table Expressions

- SQL92 supports the notion of table expressions
 - View definition bodies placed inside the SQL statement instead of a view reference! Allows complex queries to be expressed in a single table-expression (SQL thereby becomes a relationally complete language).
 - Correlation name must be specified
 - Columns may be renamed

```
SELECT AVG (n_hobbies)
FROM (SELECT last, first, COUNT (*)
      FROM hobbies
      GROUP BY last, first)
AS grouped_hobbies (last, first, n_hobbies)
WHERE grouped_hobbies.last LIKE 'N%'
```

- Why use them?
 - To avoid temporary view creation
 - To enable grouping on expressions
 - To allow host variables in the "view"

```
SELECT Source, Destination,
       MIN(New_cost)
FROM (
  SELECT Source, Destination, Carrier,
         Cost * :discount_rate AS New_cost
  FROM Flights
) AS New_price
GROUP BY Source, Destination
```

Flights

Source	Destination	Carrier	Cost
Paris	Detroit	KLM	7
Paris	New York	KLM	6
Paris	Boston	AA	8
New York	Chicago	AA	2
Boston	Chicago	AA	6
Detroit	San Jose	AA	4
Chicago	San Jose	AA	2

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Common Table Expressions

- SQL3 expands SQL/92's notion of table expressions, allowing them to be defined once and used multiple times
 - "Reusable" table expressions
- Why use them?
 - To avoid overhead of re-evaluation for each reference
 - To avoid errors associated with each reference possibly returning different results.
 - Enable recursive queries (see later charts)

For each carrier, give its lowest fare between two cities, and all carriers who offer a lower or equal lowest fare between the same two cities.

```
WITH New_Price AS (
  SELECT Source, Destination, Carrier,
         Cost * :discount_rate AS New_Cost
  FROM Flights)
SELECT a.Source, a.Destination, a.Carrier, a.New_Cost,
       b.Carrier, b.New_Cost
FROM New_Price a, New_Price b
WHERE a.Source = b.Source AND a.Destination = b.Destination AND
      a.Carrier <> b.Carrier AND a.New_Cost >= b.New_Cost
```

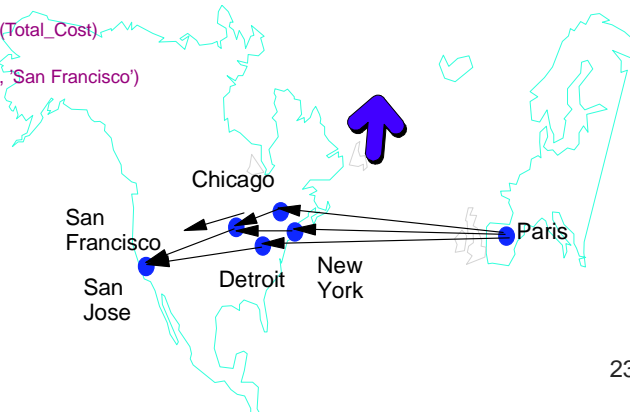
230

Recursive SQL: A First Example

Find the cheapest flight from Paris to San Jose or San Francisco.

```
WITH RECURSIVE Reachable_From (Source, Destin, Total_Cost) AS
(
  SELECT Source, Destination, Cost
  FROM Flights
  WHERE Source = 'Paris'
  UNION
  SELECT in.Source, out.Destination, in.Total_Cost + out.Cost
  FROM Reachable_From in, Flights out
  WHERE in.Destin = out.Source
)
SELECT Source, Destin, MIN(Total_Cost)
FROM Reachable_From
WHERE Destin in ('San Jose', 'San Francisco')
GROUP BY Source, Destin
```

SOURCE	DESTIN	MIN (Total_Cost)
Paris	San Fran	14
Paris	San Jose	10



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Recursive SQL: Rationale and Challenges

- What is recursive SQL?
 - self-referencing table expressions
 - self-referencing views
- Why use recursion?
 - Bill of material processing
 - Network traversals (e.g. airline routing)
- Functionality and performance benefits
- Challenge: integration into SQL
 - Syntax in analogy to Datalog
 - Advanced recursion (e.g. mutual recursion)
 - Integration with different forms of joins
 - Allowing for duplicates
 - Graph traversal in "depth first" or "breadth first"
 - Cycle control

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Recursive SQL: Advanced Use of Join Facilities

- Find all connections between two cities and the number of risky hops
 - Table `risky_cities` contains all the cities with insecure airports

```

with RECURSIVE reachable_from (source, destin, risk_count) AS
  (select source, destin, 0
   from flights
  union all
   select in.source, out.destin,
         -- Add one to the risk count for this flight.
         risk_count + case when risky_cities.name is null then 0 else 1 end
         as risk_count
   from reachable_from in
        inner join (flights out left outer join risky_cities
                   on (out.source = risky_cities.name))
        on (in.destin = out.source)
  )
select * from reachable_from

```

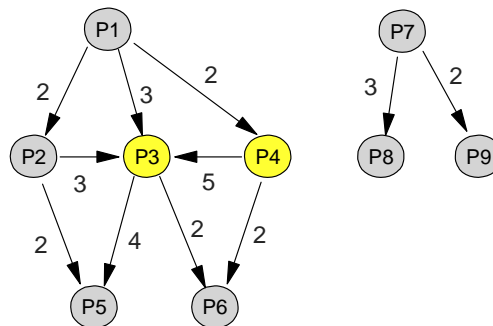
- Because not every flight goes through a risky city, we use an outer join instead of a regular join

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Bill of Material Queries

PART_PART

Major	Minor	Qty
P1	P2	2
P1	P3	3
P1	P4	2
P2	P3	3
P2	P5	2
P3	P5	4
P3	P6	2
P4	P3	5
P4	P6	2
P7	P8	3
P7	P9	2



PARTMASTER

Pno	Pname	Levelcode	IsPhantom
P1	Main	root	no
P2	Rack		no
P3	Fitting		yes
P4	Cover		yes
P5	Brace	leaf	no
P6	Angle	leaf	no

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Bill of Material Queries: Quantity Calculation

■ Preliminary quantities calculation

```
WITH RECURSIVE px (Major, Minor, Qty) AS
(
    SELECT Major, Minor, Qty
    FROM Part_Part pp
    WHERE pp.Major = 'P1'
    UNION ALL
    SELECT pp.Major, pp.Minor, px.Qty * pp.Qty
    from px, Part_Part pp
    where pp.Major = px.Minor
)
SELECT Major, Minor, Qty FROM px;
(counts along "paths"; e.g. P1 contains 4 P5 items along path P1->P2->P5)
```

■ Summarized quantities calculation

```
WITH RECURSIVE px (Major, Minor, Qty) AS
(
    SELECT Major, Minor, Qty
    FROM Part_Part pp
    WHERE pp.Major = 'P1'
    UNION ALL
    SELECT pp.Major, pp.Minor, px.Qty*pp.Qty
    FROM px, Part_Part.pp
    WHERE pp.Major = px.Minor
)
SELECT Minor, SUM(Qty)
FROM px
GROUP BY Minor;
(counts total quantity for each part)
```

这个查询不能查多图，例子中 p7, p8, p9查不出来。

```
px(major,minor,Qty)
p1,p2,2 p1->p2
p1,p3,3 p1->p3
p1,p4,2 p1->p4
p2,p3,6 p1->p2->p3
p2,p5,4 p1->p2->p5
p3,p5,12 p1->p3->p5
p3,p6,6 p1->p3->p6
p4,p3,10 p1->p4->p3
p4,p6,4 p1->p4->p6
p3,p5,24 p1->p2->p3->p5
p3,p6,12 p1->p2->p3->p6
p3,p5,40 p1->p4->p3->p5
p3,p6,20 p1->p4->p3->p6
```

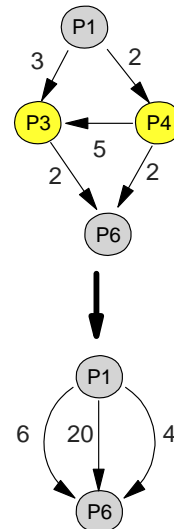
235

```
ppx(major,Arc,minor,Qty)
p1,N,p2,2 p1->p2
p1,N,p3,3
p1,N,p4,2
p2,N,p3,3
p2,N,p5,2 p2->p5
p1,Y,p5,12 p1->p5
p1,Y,p6,6 p1->p6
p1,Y,p3,10
p1,Y,p6,4 p1->p6
p2,Y,p5,12 p2->p5
p2,Y,p6,6 p2->p6
p1,Y,p5,40 p1->p5
p1,Y,p6,20 p1->p6
```

Bill of Material Queries: Graph Restructuring

■ Eliminating intermediate 'phantom' parts

```
WITH RECURSIVE PPX (Major, IsNewArc, Minor, Qty) AS
(
    SELECT Major, pm.isPhantom, Minor, Qty
    from Part_Part pp, Partmaster pm
    where pp.Major = 'P1' and pp.Major = pm.Pno
    AND pm.isPhantom = 'NO'
    UNION ALL
    SELECT case pm.isPhantom
    WHEN 'YES' THEN ppx.Major ELSE pp.Major END, --- Major
    pm.isPhantom, --- IsNewArc
    pp.Minor, --- Minor
    CASE pm.isPhantom
    WHEN 'YES' THEN ppx.Qty * pp.Qty ELSE pp.Qty END,--- Qty
    FROM ppx, Part_Part pp, Partmaster pm
    WHERE pp.Major = ppx.Minor and pp.Major = pm.Pno
)
SELECT ppx.Major, ppx.Minor, ppx.Qty, ppx.IsNewArc
FROM ppx, Partmaster pm
WHERE ppx.Minor = pm.Pno AND
pm.isPhantom = 'NO'
```



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Bill of Material Queries: Generation of Search Order Columns

- Parts Explosion with generated column for "depth-first" search order (in essence: concatenated key info)

```
WITH RECURSIVE px (Major, Minor) AS
(
  SELECT Major, Minor FROM Part_Part pp WHERE pp.Major = 'P1'
  UNION ALL
  SELECT pp.Major, pp.Minor FROM px, Part_Part pp WHERE pp.Major = px.Minor
) SEARCH DEPTH FIRST BY Major, Minor SET CatenatedKey
SELECT Major, Minor
FROM px
ORDER BY CatenatedKey
```

- Parts Explosion with generated column for "breadth-first" search order (level and key info)

```
WITH RECURSIVE px (Major, Minor) AS
(
  SEELCT Major, Minor FROM Part_Part pp WHERE pp.major = 'P1'
  UNION ALL
  SELECT pp.Major, pp.Minor FROM px, Part_Part pp WHERE pp.Major = px.Minor
) SEARCH BREADTH FIRST BY Major, Minor SET OrderColumn
SELECT Major, Minor
FROM px
ORDER BY OrderColumn;
```

- BREADTH or DEPTH feature only applicable for "simple" recursive queries
- Results in query rewrite

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Bill of Material Queries: Protection against Looping

- Duplicate suppression avoids cycles
- Use of CYCLE clause for simple recursive queries
 - ▶ Effects rewrite of query s.t. traversed paths are maintained (column path) using "navigator columns" (here column Minor), and rows with duplicate paths are marked (see column CycleMark)
 - ▶ Query techniques used in rewrite process also usable "manually"

```
WITH RECURSIVE px (Major, Minor) AS
(
  SELECT Major, Minor
  FROM Part_Part pp
  WHERE pp.Major = 'P1'
  UNION ALL
  SELECT pp.Major, pp.Minor,
  FROM px, Part_Part pp
  WHERE pp.Major = px.Minor
) CYCLE Minor SET CycleMark TO '1' DEFAULT '0' USING Path
SELECT Major, Minor
FROM px
ORDER BY Major, Minor DESC ;
```

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▼ Bill of Material queries: Graph Pruning Examples

■ "where-used"

```
WITH RECURSIVE px (Major, Minor) AS
(
  SELECT Major, Minor
  FROM Part_Part pp
  WHERE pp.Minor = 'P5'
  UNION
  SELECT pp.Major, pp.Minor
  FROM px, Part_Part pp
  WHERE pp.Minor = px.Major)
SELECT Major, Minor FROM px;
```

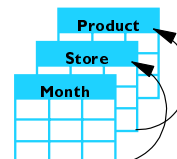
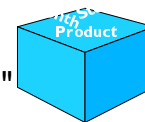
■ Parts explosion excluding base parts

```
WITH RECURSIVE px (Major, Minor, Pname, Levelcode) AS
(
  SELECT Major, Minor, pm.pname, pm.Levelcode
  FROM Part_Part pp, Partmaster pm
  WHERE pp.Major = 'P1'
  AND pp.Minor = pm.Pno
  UNION ALL
  SELECT pp.Major, pp.Minor, pm.Pname, pm.Levelcode
  FROM px, Part_Part pp, partmaster
  WHERE pp.Major = px.Minor
  AND pp.Minor = pm.Pno
  AND px.Levelcode <> 'LEAF')
SELECT Major, Minor, Pname, Levelcode FROM px;
```

239

▼ SQL99 OLAP SQL Extensions

- Extension to GROUP BY clause
- Produces "super aggregate" rows
- ROLLUP equivalent to "control breaks"
- CUBE equivalent to "cross tabulation"
- GROUPING SETS equivalent to multiple GROUP BYs
- Provides "data cube" collection capability
 - ▶ Often used with data visualization tool

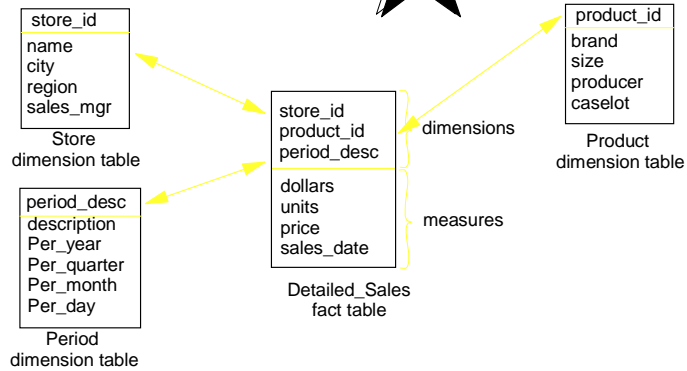


240

OLAP Schema

- Typically uses a "STAR" structure

- Dimension tables tend to be small
- Fact table tends to be huge



```
CREATE VIEW Sales AS
(SELECT ds.*, YEAR (sales_date) AS year, MONTH (sales_date) AS month,
DAY (sales_date) AS day
FROM (Detailed_Sales NATURAL JOIN Store NATURAL JOIN Product
NATURAL JOIN Period) ds
```

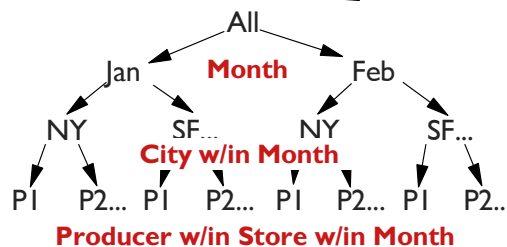
241

ROLLUP

- Extends grouping semantics to produce "subtotal" rows
 - Produces "regular" grouped rows
 - Produces same groupings reapplied down to grand total



```
SELECT month, city, producer, SUM(units) AS sum_units
FROM Sales
WHERE year = 1998
GROUP BY ROLLUP (month, city, producer)
```



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▼ ROLLUP

Find the total sales per region and sales manager during each month of 1996, with subtotals for each month, and concluding with the grand total:

```
SELECT month, region, sales_mgr, SUM (price)
FROM Sales
WHERE year = 1996
GROUP BY ROLLUP (month, region, sales_mgr)
```

MONTH	REGION	SALES_MGR	SUM(price)
April	Central	Chow	25 000
April	Central	Smith	15 000
April	Central	-	40 000
April	NorthWest	Smith	15 000
April	NorthWest	-	15 000
April	-	-	55 000
May	Central	Chow	25 000
May	Central	-	25 000
May	NorthWest	Smith	15 000
May	NorthWest	-	15 000
May	-	-	40 000
-	-	-	95 000

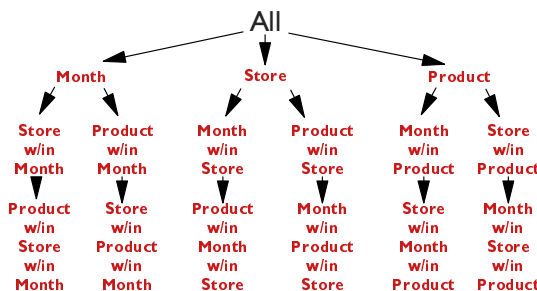
243

▼ CUBE

- Further extends grouping semantics to produce multidimensional grouping and "subtotal" rows
 - Superset of ROLLUP
 - Produces "regular" grouped rows
 - Produces same groupings reapplied down to grand total
 - Produces additional groupings on all variants of the CUBE clause



```
SELECT month, city, product_id, SUM(units)
FROM Sales
WHERE year = 1998
GROUP BY CUBE (month, city, product.id)
```



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SELECT ... GROUP BY CUBE

```
SELECT month, region, sales_mgr, SUM(price)
FROM Sales
WHERE year = 1996
GROUP BY CUBE (month, region, sales_mgr)
```

MONTH	REGION	SALES_MGR	SUM(price)
April	Central	Chow	25 000
April	Central	Smith	15 000
April	Central	-	40 000
April	NorthWest	Smith	15 000
April	NorthWest	-	15 000
April	-	Chow	25 000
April	-	Smith	30 000
April	-	-	55 000
May	Central	Chow	25 000
May	Central	-	25 000
May	NorthWest	Smith	15 000
May	NorthWest	-	15 000
May	-	Chow	25 000
May	-	Smith	15 000
May	-	-	40 000
-	Central	Chow	50 000
-	Central	Smith	15 000
-	Central	-	65 000
-	NorthWest	Smith	30 000
-	NorthWest	-	30 000
-	-	Chow	50 000
-	-	Smith	45 000
-	-	-	95 000

245

GROUPING SETS

- Multiple "groupings" in a single pass
 - Used in conjunction with usual aggregation (MAX, MIN, SUM, AVG, COUNT, ...)
 - Allows multiple groups e.g. (month, region) and (month, sales_mgr)
 - Result can be further restricted via HAVING clause

Find the total sales during each month of 1996, per region and per sales manager:

```
SELECT month, region, sales_mgr, SUM(price)
FROM Sales
WHERE year = 1996
GROUP BY GROUPING SETS ((month, region),
                          (month, sales_mgr))
```

MONTH	REGION	SALES_MGR	SUM(SALES)
April	Central	-	40 000
April	NorthWest	-	15 000
April	-	Chow	25 000
April	-	Smith	30 000
May	Central	-	25 000
May	NorthWest	-	15 000
May	-	Chow	25 000
May	-	Smith	15 000

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▼ Generating Grand Total Rows

- Special syntax available to include a "grand total" row in the result
 - Grand totals are generated implicitly with ROLLUP and CUBE operations
 - Syntax allows grand totals to be generated without additional aggregates

Get total sales by month, region, and sales manager and also the **overall total sales**:

```
SELECT month, region, sales_mgr, SUM (price)
FROM Sales
WHERE year = 1996
GROUP BY GROUPING SETS ( (month, region, sales_mgr),
                          ( ) )
```

MONTH	REGION	SALES_MGR	SUM(SALES)
April	Central	Chow	25 000
April	Central	Smith	15 000
April	NorthWest	Smith	15 000
May	Central	Chow	25 000
May	NorthWest	Smith	15 000
-	-	-	95 000

247

▼ The GROUPING Function

- New column function
 - Allows detection of rows that were generated during the execution of CUBE and ROLLUP i.e. generated nulls to be distinguished from naturally occurring ones
- Example:

Run a rollup, and flag the generated rows...

```
SELECT month, region, sales_mgr, SUM(price), GROUPING(sales_mgr)
FROM Sales
WHERE year = 1996
GROUP BY ROLLUP (month, region, sales_mgr)
```

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Result...

```
SELECT month, region, sales_mgr, SUM(price), GROUPING(sales_mgr) AS
GROUPED
FROM Sales
WHERE year = 1996
GROUP BY ROLLUP (month, region, sales_mgr)
```

MONTH	REGION	SALES_MGR	SUM(SALES)	GROUPED
April	Central	Chow	25 000	0
April	Central	Smith	15 000	0
April	Central	-	40 000	1
April	NorthWest	Smith	15 000	0
April	NorthWest	-	15 000	1
April	-	-	55 000	1
May	Central	Chow	25 000	0
May	Central	-	25 000	1
May	NorthWest	Smith	15 000	0
May	NorthWest	-	15 000	1
May	-	-	40 000	1
-	-	-	95 000	1

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Selecting Nongrouped Columns

- Nongrouped columns can sometimes be selected based on functional dependencies:

```
SELECT e.deptno, d.location, AVG (e.salary) AS average
FROM Emp e , Dept d
WHERE e.deptno = d.deptno
GROUP BY e.deptno
```



e.deptno determines d.deptno (equals in WHERE clause), and d.deptno determines d.location (deptno is PK of Dept); therefore, d.deptno and d.location are consistent within any group. This is functional dependency analysis in action.



```
SELECT e.deptno, e.name, AVG (e.salary) AS Average
FROM Emp e, Dept d
WHERE e.deptno = d.deptno
GROUP BY e.deptno
```

250

▼ UPDATE through UNION

People

LNAME	FNAME	NICK
Holland	William	Bill
Zysko	William	Willy

Hobbies

LAST	FIRST	HOBBY
Holland	William	Fishing
Zysko	William	Dancing
Smith	(null)	Painting

```
CREATE VIEW people_or_hobbies
AS SELECT fname, lname
```

```
FROM people
```

```
UNION ALL
```

```
SELECT first, last
```

```
FROM hobbies;
```

people_or_hobbies

LNAME	FNAME
Smith	(null)
Holland	William
Holland	William
Zysko	William
Zysko	William

```
UPDATE people_or_hobbies
```

```
SET fname='Wilhemina',
```

```
lname='Jing'
```

```
WHERE fname='Zysko' and
```

```
lname='William' ;
```

People

LNAME	FNAME	NICK
Holland	William	Bill
Jing	Wilhemina	Willy

Hobbies

LAST	FIRST	HOBBY
Holland	William	Fishing
Jing	Wilhemina	Dancing
Smith	(null)	Painting

251

▼ UPDATE through JOIN

People

LNAME	FNAME	NICK
Holland	William	Bill
Zysko	William	Willy

Hobbies

LAST	FIRST	HOBBY
Holland	William	Fishing
Zysko	William	Dancing
Smith	(null)	Painting

```
DECLARE c1 CURSOR FOR
WITH people_and_hobbies AS
  (people INNER JOIN hobbies
   ON (fname=first AND lname=last))
SELECT *
FROM people_and_hobbies;
```

people_and_hobbies

LNAME	FNAME	NICK	LAST	FIRST	HOBBY
Holland	William	Bill	Holland	William	Fishing
Zysko	William	Willy	Zysko	William	Dancing

← c1

```
UPDATE person_and_hobbies
```

```
SET hobby='birdwatching'
```

```
WHERE CURRENT OF c1;
```

people_and_hobbies

LNAME	FNAME	NICK	LAST	FIRST	HOBBY
Holland	William	Bill	Holland	William	birdwatching
Zysko	William	Willy	Zysko	William	Dancing

252

▼ INSERT through JOIN

People

LNAME	FNAME	NICK
Holland	William	Bill
Zysko	William	Willy

Hobbies

LAST	FIRST	HOBBY
Holland	William	Fishing
Zysko	William	Dancing
Smith	(null)	Painting

```
CREATE VIEW Dancers AS
people JOIN hobbies
ON (fname=first AND last=lname)
WHERE hobby='Dancing'
WITH CHECK OPTION;
```

Dancers

LNAME	FNAME	NICK	LAST	FIRST	HOBBY
Zysko	William	Willy	Zysko	William	Dancing

```
INSERT INTO dancers
VALUES ('John', 'Harshman', 'John'
'John', 'Harshman', 'Dancing');
```

Dancers

LNAME	FNAME	NICK	LAST	FIRST	HOBBY
Zysko	William	Willy	Zysko	William	Dancing
Harshman	John	John	Harshman	John	Dancing

253

▼ Named Expressions

- Provide name for column in result table
- Can be used in ORDER BY

```
DECLARE payroll CURSOR FOR
SELECT name, base_salary + commission AS pay
FROM employees
ORDER BY pay
```

254

▼ Scrollable Cursors

- In SQL89, FETCH always retrieves “next” row
- In SQL92, cursors are scrollable:
 - Allows both forward and backward movement of the cursor
 - Allows skipping of rows

```
EXEC SQL DECLARE c SCROLL CURSOR FOR SELECT ...;  
EXEC SQL OPEN c ;  
EXEC SQL FETCH ABSOLUTE 10 FROM c INTO ...;  
EXEC SQL FETCH RELATIVE 32 FROM C INTO ...;  
EXEC SQL FETCH PRIOR FROM C INTO ...;
```

- FETCH options are:
 - FIRST
 - LAST
 - NEXT
 - PRIOR
 - ABSOLUTE n
 - RELATIVE n

255

▼ Scrollable Cursor Example

FIRST
RELATIVE -3

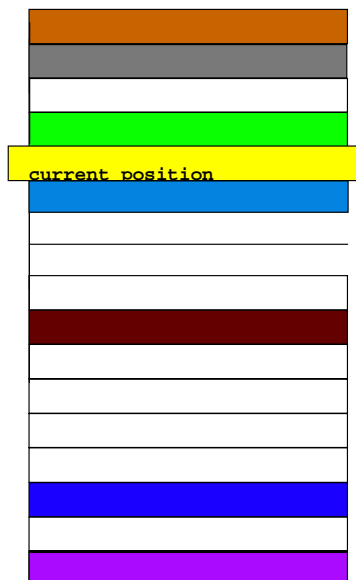
PRIOR

NEXT

ABSOLUTE 10

RELATIVE 10

LAST



256

▼ READ ONLY and FOR UPDATE OF Cursors

- READ ONLY and FOR UPDATE
 - Allows an explicit specification of the columns of a cursor that may be updated

```
EXEC SQL DECLARE c1 CURSOR FOR  
SELECT lname, fname FROM people  
READ ONLY ;
```

```
EXEC SQL DECLARE c2 CURSOR FOR  
SELECT lname, fname, nick FROM people  
FOR UPDATE OF nick;
```

257

▼ Cursor Sensitivity

- SQL92 feature
- New in SQL99: **ASENSITIVE**
 - Same as SQL92, when neither SENSITIVE nor INSENSITIVE specified
 - Effect implementation-defined
- Purpose of cursor sensitivity: controls whether cursor Cx can see changes which have been
 - Affected in **same** TX (say TX1)
 - Not caused by CX itself (e.g. by cursor CY; by INSERT statement)

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▼ Cursor Sensitivity (cont.)

- SENSITIVE: changes are visible
- INSENSITIVE: changes are invisible
 - Cursor is READ ONLY
- Example:

```
EXEC SQL;  
DECLARE C CURSOR SENSITIVE FOR  
SELECT * FROM People;
```
- Note: Visibility of changes from foreign TXs also controlled by isolation level
- If cursor is holdable and kept open:
 - SENSITIVE: changes of TX1 and subsequent TX2 remain/become visible
 - INSENSITIVE: these changes are not visible

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▼ Holdable cursors

- New in SQL99
- Let TXC be the TX in which a cursor C is created
- Classical (non-holdable) cursors are closed when TXC is terminated (i.e. they do not survive TXC)
- Open holdable cursors
 - Remain open when TX is committed
 - Are closed and destroyed when
 - TXC is rolled back
 - Session is terminated

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▼ ORDER BY Extensions

- ORDER BY on columns not in the select list

```
DECLARE CURSOR FOR
  SELECT empno, name
  FROM employee
  ORDER BY salary DESC
```

- ORDER BY expressions

```
DECLARE C2 CURSOR FOR
  SELECT empno, name
  FROM employee
  ORDER BY salary + bonus ASC
```

261

▼ Temporary Tables

- Used to increase concurrency and decrease processing costs
 - May be updated even if the transaction has an access mode of read-only
- Created Global Temporary Tables
 - Table definition is persistent (i.e., exists within a schema)
 - A new instance of the table is created for each SQL-session
 - Table may be shared by procedures in multiple modules in a the same session

```
CREATE GLOBAL TEMPORARY TABLE VIP_accounts
(account_id INTEGER,
balance money,
type account_type)
ON COMMIT PRESERVE ROWS;    --- DELETE rows also supported
```

- Created Local Temporary Tables
 - Distinct instances are created for each SQL-session/module combination

```
CREATE LOCAL TEMPORARY TABLE VIP_accounts
(account_id INTEGER,
balance money,
type account_type)
ON COMMIT DELETE ROWS;
```

262

▼ Temporary Tables

- **Declared Local Temporary Tables**
 - Table definition is not persistent (i.e., exists only in the module it is defined)
 - An instance is created for each SQL-session/module combination

```
MODULE ...
LANGUAGE ...
SCHEMA ... AUTHORIZATION ...
DECLARE LOCAL TEMPORARY TABLE MODULE.t1
(account_id INTEGER,
balance money,
type account_type)
ON COMMIT DELETE ROWS;
```

- **Constraints between temporary tables and persistent tables**

Source Table		Target Table
base	may not reference	any temporary
any temporary	may not reference	base
created global	may reference	created global
created local	may reference	created global
created local	may reference	created local
declared local	may reference	created global
declared local	may reference	created local
declared local	may reference	declared local

263

▼ Roles

- New in SQL99; benefits:
 - Simplifies definition of complex sets of privileges
- Roles are created
 - Note: definition of users implementation-defined

```
CREATE ROLE Auditor
CREATE ROLE AuditorGeneral
```
- Roles may be assigned to users & roles


```
GRANT Auditor TO AuditorGeneral
WITH ADMIN OPTION
GRANTED BY CURRENT ROLE

GRANT Auditor TO Smith
```
- Controllable whether to grant as user or role

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▼ Roles (cont.)

- Roles (like users) may own objects
- As to users, privileges may be granted to roles
 - `Grant INSERT ON TABLE Budget TO Auditor`
 - This privilege also among privileges of AuditorGeneral
- A role R identifies a set of privileges:
 - Those directly granted to R
 - Those of the roles granted to R

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▼ Roles (cont.)

- At any time there is at least either a valid current user or a valid current role
- Current user can be set
 - Invalidates current role
 - `SET SESSION AUTHORIZATION 'JDOE'`
- Current role can be set or invalidated
 - `SET ROLE Auditor`
- Operations (e.g. INSERT) determine the kind of required privileges
 - Often: union of user's and role's privileges
- Session context maintains stack of user and role identifier pairs
 - New pair is pushed when externally invoked procedure is executed
 - Temporarily makes client module identifier the current user
 - Enables invoker's rights in a limited fashion

266

▼ Error Handling: SQLSTATE

- In SQL/89
 - ▶ SQLCODE integer value: 0, +100, negative values deprecated feature
 - ▶ 5-character SQLSTATE may be used in place of SQLCODE
 - 2 characters represent class
 - 3 characters represent subclass
 - ▶ Classes and subclasses reserved for vendor extensions

SQLSTATE	SQLCODE	Description
'00000'	0	Successful completion
'02000'	100	No data
'22001'	-n	Data exception - string data, right truncation
'22012'	-n	Data exception - division by zero

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▼ Error Handling: Diagnostics Area

- Records information about exceptions, warnings, no data, and successful completion
- Can retain information about several exceptions
 - ▶ Execution of a statement may raise multiple exceptions
 - ▶ SQLSTATE, relevant catalog, schema, or table, relevant constraint, relevant cursor, message text

```
EXEC SQL BEGIN DECLARE SECTION;
int n, i;
char sqlstate [5], s [5];
EXEC SQL END DECLARE SECTION;

report_error ()
{
    EXEC SQL GET DIAGNOSTICS :n = NUMBER;
    for (i = 1, i <= n, i++)
    {
        EXEC SQL GET DIAGNOSTICS EXCEPTION :i
            :s = RETURNED_SQLSTATE, ... ;
        printf (...);
    }
}
```

268

▼ Transactions in SQL92

- Transactions start implicitly and end with COMMIT WORK or ROLLBACK WORK
 - ▶ Attributes
 - Access mode: READ ONLY and READ WRITE
 - Isolation level: READ UNCOMMITTED, READ COMMITTED, REPEATABLE READ, and SERIALIZABLE
 - Diagnostics area size

Isolation level	Dirty read	Non-repeatable read	Phantom
READ UNCOMMITTED	possible	possible	possible
READ COMMITTED	not possible	possible	possible
REPEATABLE READ	not possible	not possible	possible
SERIALIZABLE	not possible	not possible	not possible

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▼ Transactions in SQL92 (cont.)

- SET TRANSACTION statement cannot be executed while a transaction is active
**SET TRANSACTION READ WRITE,
READ COMMITTED
DIAGNOSTICS SIZE 20;**
- An implementation does not have to support DML and DDL statements mixed within a single transaction
- An SQL-transaction may be part of an encompassing transaction
 - ▶ If an SQL-transaction has been started by a non-SQL agent, then a COMMIT statement will raise an exception
- Keyword WORK is optional

270

Transaction Management: New in SQL99

- New statements for
 - Explicitly starting TXs
 - Also sets TX characteristics
 - Establishing savepoints
 - Destroying savepoints
- Extensions of SQL 92 features
 - Savepoint processing in commit, rollback
 - CHAIN option for commit and rollback
 - Initiates new TX
 - LOCAL option of set TX statement
 - If TX served by n>1 servers ("TX branches")
 - Allows different "branch" characteristics

271

Savepoint: Example

- Insert row into table *People* and establish savepoint

```
INSERT INTO People
VALUES('Doe', 'John', 'Hans');
SAVEPOINT SP1
```
- Change that row

```
UPDATE People SET Nick = 'Jean'
WHERE LName = 'Doe'
```
- Undo the last change

```
ROLLBACK TO SAVEPOINT SP1
```
- Note: TX remains open; Nickname reset to 'Hans'

272

▼ Connections

- Association between an SQL-client and an SQL-server.
- There is an SQL-session associated with each connection.

```
env = "IBMSYS" ;  
connect = "STLconnection" ;  
user = "Todd" ;  
EXEC SQL CONNECT TO :env AS :connect USER :user
```

```
...  
EXEC SQL COMMIT;  
env = "IBMSYS2";  
EXEC SQL SET CONNECTION :env;
```

- Transactions that affect more than one SQL-environment do not have to be supported.

273

▼ SQL Flagger

- Used to flag:
 - ▶ Extensions to the level of SQL/99 chosen
 - ▶ Conforming language that is being processed in a non-conforming way
- Must be provided with an SQL implementation
- Provides one or more of the following "levels of flagging":
 - ▶ Core SQL flagging
 - ▶ Part SQL flagging
 - ▶ Package SQL flagging
- Provides one or more of the following "extent" options:
 - ▶ Syntax only
 - ▶ Catalog lookup

274

▼ Module Language

- Module definition

```
module read
Language C
Authorization reader
DECLARE people CURSOR FOR
    SELECT last, first
    FROM      hobbies
    WHERE     hobbies =:h
PROCEDURE open_people (SQLSTATE, :h CHAR (5));
    OPEN people;
PROCEDURE fetch_people (SQLSTATE, :last CHAR(20), :first CHAR(20));
    FETCH people INTO :last, :first;
PROCEDURE close_people SQLSTATE;
    CLOSE people;
```

- Application program

```
main()
}
char SQLSTATE[6];
char last [21], first [21];
OPEN_PEOPLE (SQLSTATE, "travel");
while...
    FETCH_PEOPLE (SQLSTATE, last, first);
}
```

275

▼ SQL99 PSM Overview

- Procedural Extensions

- ▶ Improve performance in centralized and client/server environments
 - Multiple SQL statements in a single EXEC SQL
 - Multi-statement procedures, functions, and methods
- ▶ Gives great power to DBMS
 - Several, new control statements (procedural language extension) (begin/end block, assignment, call, case, if, loop, for, singal/resignal, variables, exception handling)
- ▶ SQL-only implementation of complex functions
 - Without worrying about security ("firewall")
 - Without worrying about performance ("local call")
- ▶ SQL-only implementation of class libraries

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SQL/PSM

- Includes two major aspects:
 - Procedural extensions (aka control statements) - features from block-structured languages, including exception handling.
 - SQL-server modules - groups of SQL-invoked routines managed as named, persistent objects.
- Consider a C program with embedded SQL statements:

```
void main
EXEC SQL INSERT INTO employee
VALUES (...);
EXEC SQL INSERT INTO department
VALUES (...);
}
```

- Using PSM-96 procedural extensions, the same program can be written as:

```
void main
{
EXEC SQL
BEGIN
INSERT INTO employee VALUES (...);
INSERT INTO department VALUES (...);
END;
}
```

277

SQL/PSM (cont.)

- If we create a SQL procedure first:

```
CREATE PROCEDURE proc1 ()
{
BEGIN
INSERT INTO employee VALUES (...);
INSERT INTO department VALUES (...);
END;
}
```

- Then the embedded program can be written as

```
void main
{
EXEC SQL CALL proc1();
}
```

278

SQL Procedural Language Extensions

- Compound statement
- SQL variable declaration
- If statement
- Case statement
- Loop statement
- While statement
- Repeat statement
- For statement
- Leave statement
- Return statement
- Call statement
- Assignment statement
- Signal/resignal statement
- BEGIN ... END;
- DECLARE var CHAR (6);
- IF subject (var <> 'urgent') THEN ... ELSE ...;
- CASE subject (var) WHEN 'SQL' THEN ... WHEN ...;
- LOOP < SQL statement list> END LOOP;
- WHILE i<100 DO END WHILE;
- REPEAT ... UNTIL i<100 END REPEAT;
- FOR result AS ... DO ... END FOR;
- LEAVE ...;
- RETURN 'urgent';
- CALL procedure_x (1,3,5);
- SET x = 'abc';
- SIGNAL division_by_zero

279

Compound Statement

- A compound statement is a group of SQL statements to be executed sequentially.
`<compound statement> :: =
[<beginning label> <colon>]
BEGIN [[NOT] ATOMIC]
[<local declaration list>]
[<local cursor declaration list>]
[<local handler declaration list>]
[<SQL statement list>]
END <ending label>`
- Example:
`BEGIN
UPDATE accounts SET balance = balance-100
WHERE ...;
INSERT INTO account_history
(SELECT account#, CURRENT_DATE, 'debit', 100 FROM
accounts WHERE ...);
END`

280

▼ Compound Statement (cont.)

- A compound statement may specify ATOMIC or NOT ATOMIC. (If unspecified, NOT ATOMIC is implicit.)

```
BEGIN ATOMIC
UPDATE accounts SET balance = balance-100
WHERE ...;
INSERT INTO account_history
(SELECT account#, CURRENT_DATE, 'debit', 100 FROM accounts
WHERE ...);
END
```

- Assume UPDATE statement succeeds, but INSERT statement fails.
- If NOT ATOMIC is specified or implied, effects of UPDATE statement persist, but effects of INSERT statement are undone.
- If ATOMIC is specified, effects of both UPDATE and INSERT statement are undone if either of them fail. Does not imply transaction rollback.

281

▼ Compound Statement (cont.)

- Variables, cursors, conditions, and handlers can be declared inside a compound statement.

```
BEGIN ATOMIC
DECLARE account,branch INTEGER DEFAULT 0;
DECLARE curs1 CURSOR FOR ...;
DECLARE too_many_accounts CONDITION FOR SQLSTATE VALUE
'SS000';
DECLARE UNDO HANDLER FOR too_many_accounts BEGIN ... END;
...
END
```

- Variables, cursors, conditions, and condition handlers declared inside a compound statement have the scope and lifetime of the containing compound statement.
- A variable declaration must declare the name and data type. It can optionally specify a default value.
- If a condition declaration explicitly specifies a SQLSTATE value, it associates a condition name with that SQLSTATE value; otherwise, it associates a condition name with a predefined SQLSTATE value (45000).

282

▼ Compound Statement (cont.)

- Compound statements can be nested.
- Normal scope rules apply, i.e., declarations in an inner compound statement occludes the declarations with the same name in an outer compound statement.
- A variable can be of any SQL data type. NULL is a valid value for a variable.
- A compound statement is associated with a label; if unspecified, an implementation-dependent label is implicit.
- The body of a compound statement may contain:
 - DDL statements
 - DML statements
 - Control statements
 - COMMIT and ROLLBACK statements (not allowed inside an ATOMIC compound statement)
 - Session and connection management statements
 - GET DIAGNOSTICS statements
 - Dynamic SQL statements

283

▼ Assignment Statement

- A variable can be assigned a value either by a SELECT ... INTO or an assignment statement.
- An assignment statement uses the SET keyword.

```
DECLARE bal DECIMAL(15,2);
SELECT balance INTO bal FROM accounts WHERE ...;
SET bal = 0.00;
SET bal = (SELECT balance FROM accounts WHERE ...);
```

284

▼ LEAVE Statement

- Terminates the execution of labelled statements.

```
outer: BEGIN
DECLARE bal DECIMAL(15,2);
SELECT balance INTO bal FROM accounts WHERE ...;
IF (bal -10.0) < 0 THEN
BEGIN
CALL print_message(...);
LEAVE outer;
END;
...
END;
```

285

▼ IF Statement

- Conditional execution of statements.

```
BEGIN
DECLARE bal DECIMAL(15,2);
SELECT balance INTO bal FROM accounts WHERE ...;
IF bal BETWEEN 0 AND 1000
THEN ...
ELSEIF bal BETWEEN 1001 AND 2500
THEN...
ELSE ...
END IF;
END;
```

286

▼ CASE Statement

- Simple CASE statement: selects an execution path based on the result of an expression.

```
CASE (SELECT status FROM accounts WHERE ...)  
WHEN 'VIP' THEN ...  
WHEN 'BUSINESS' THEN ...  
ELSE ...  
END CASE;
```

- Searched CASE statement: selects an execution path based on the truth value of a predicate.

```
SELECT balance INTO bal FROM accounts WHERE ...;  
CASE  
WHEN bal BETWEEN 0 AND 1000 THEN ...  
WHEN bal BETWEEN 1001 AND 2500 THEN ...  
ELSE ...  
END CASE;
```

- In both forms, specification of ELSE case is optional. If ELSE case is unspecified, and none of the branches evaluates to TRUE, then an exception is raised.

287

▼ LOOP Statement

- Executes a group of statements repeatedly.
- LOOP statement is a labelled statement.
- Does not allow termination test; LEAVE statement is used to exit the LOOP statement.

```
DECLARE X INTEGER DEFAULT 0;  
L1: LOOP  
IF X > 10 THEN LEAVE L1;  
SET X = X + 1;  
END LOOP;
```

288

▼ WHILE Statement

- Executes a group of statements repeatedly.
- WHILE statement is a labelled statement.
- Allows termination test; terminates when the termination test evaluates to FALSE or UNKNOWN.

```
DECLARE X INTEGER DEFAULT 0;  
WHILE X <= 10 DO  
SET X = X + 1;  
END WHILE;
```

289

▼ REPEAT Statement

- Executes a group of statements repeatedly.
- REPEAT statement is a labelled statement.
- Allows termination test; terminates when the termination test evaluates to TRUE.

```
DECLARE X INTEGER DEFAULT 0;  
REPEAT  
SET X = X + 1;  
UNTIL X = 10  
END REPEAT;
```

290

▼ FOR Statement

- Executes a group of statements repeatedly.
- FOR statement is a labelled statement.
- Must be associated with a query expression; terminates after the group of statements is executed for every row in the result of query expression.

```
DECLARE X INTEGER DEFAULT 0;  
FOR L1 AS SELECT balance FROM accounts DO  
SET X = X + balance;  
END FOR;
```

- Body of a FOR statement is not allowed to contain a LEAVE statement that refers to L1.
- A cursor is implicitly opened at the beginning of execution; closed automatically at the end of execution.
- It is possible to specify a name for the implicit cursor:

```
FOR L1 AS curs1 CURSOR FOR  
SELECT * FROM accounts WHERE balance = 0 DO  
DELETE FROM accounts WHERE CURRENT OF curs1;  
END FOR;
```
- The body of FOR statement is not allowed to contain a OPEN, FETCH, or CLOSE statement that refers to curs1.

291

▼ ITERATE Statement

- Allowed inside a LOOP, WHILE, REPEAT and FOR statement only.
- Terminates the current iteration through the loop.

292

▼ Condition Handling

- A compound statement may contain any number of condition handlers.
 - ▶ A condition handler must specify
 - ▶ A set of conditions it is prepared to handle
 - ▶ Action to perform to handle the condition
 - ▶ Where to resume the execution after handling the condition
- Action specified in a condition handler can be any SQL statement, including a compound statement.

```
BEGIN
DECLARE low_balance CONDITION;
DECLARE CONTINUE HANDLER FOR low_balance
BEGIN
...
END;
...
END
```

- A condition handler gets executed automatically when a condition it is prepared to handle is detected anytime during the execution of the containing compound statement.

-
-

293

▼ Condition Handling (cont.)

- Conditions specified in a condition handler can be:
 - ▶ SQLSTATE value
 - ▶ Condition name
 - ▶ SQLEXCEPTION (all SQLSTATE values with class other than 00, 01, or 02)
 - ▶ SQLWARNING (all SQLSTATE values with class 01)
 - ▶ NOT FOUND (all SQLSTATE values with class 02)
- A condition handler may specify:
 - ▶ CONTINUE: resume the execution with the statement following the one that raised the condition.
 - ▶ EXIT: resume the execution with the statement following the compound statement.
 - ▶ UNDO: (allowed inside ATOMIC compound statements only) undo the effects of the compound statement and resume the execution with the statement following the compound statement.
- Conditions can be raised implicitly by the system or explicitly by means of SIGNAL or RESIGNAL statements.

294

▼ Condition Handling (cont.)

```
BEGIN
DECLARE CONTINUE HANDLER FOR low_balance
BEGIN
...
IF ... THEN RESIGNAL db_inconsistency END IF;
END;
...
END
```

- If the RESIGNAL statement specifies a condition name, then a new condition is pushed onto the diagnostics area, which becomes the active condition; otherwise, the condition that caused the handler to execute continues to be the active condition.
- The condition handler and the compound statement terminate their execution and execution resumes with the condition handler associated with the outer compound statement.
- An implicit RESIGNAL statement gets executed if a compound statement or a handler action completes with a condition other than successful completion.

295

▼ Embedding of Control Statements

- All control statements can be embedded in a host language program.
- Only CALL statement is allowed to be dynamically prepared and executed.

296

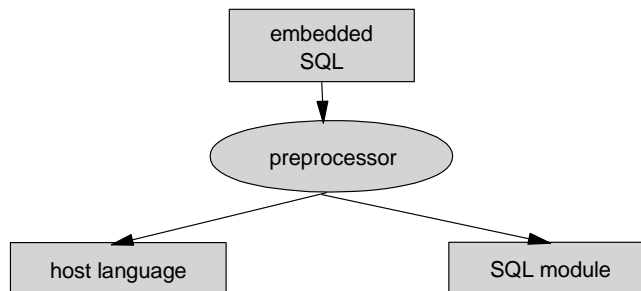
SQL99 Bindings Overview

- Embedded SQL
 - ADA
 - C
 - Cobol
 - Fortran
 - Mumps
 - Pascal
 - PL/I
- Dynamic SQL
- Direct SQL

297

Embedded SQL

- An embedded host language program is transformed into a pure host language program and an "abstract" SQL module



- SQL modules are the way used for the standards to describe the semantics of embedded SQL (don't need to be implemented this way)

298

▼ Dynamic SQL

- Needed when the tables, columns, or predicates are not known when the application is written
- Execute statement immediately (once)
`s = "INSERT INTO people VALUES ('Harris', ...)";`
`EXEC SQL EXECUTE IMMEDIATE :s;`
- Execute statement more than once
`EXEC SQL PREPARE stmt FROM :s;`
`EXEC SQL EXECUTE stmt;`
`EXEC SQL EXECUTE stmt;`
- Dynamic parameter makers
`s = "INSERT INTO people VALUES (?, ?, ...)";`
`EXEC SQL PREPARE stmt FROM :s;`
`Iname = "Harris";`
`fname = "Todd";`
`EXEC SQL EXECUTE stmt USING :Iname, :fname, ... ;`

299

▼ Dynamic SQL

- Descriptor area can be used if the number of dynamic parameters is not known.
- Descriptor area is an encapsulated structure managed by the DBMS
- Different from commercial practice (where application allocates a SQLDA)
`s = "INSERT INTO people VALUES (?, ?, ...)";`
`EXEC SQL PREPARE stmt FROM :s ;`
`EXEC SQL ALLOCATE DESCRIPTOR 'input_params';`
`EXEC SQL DESCRIBE INPUT stmt`
`INTO SQL DESCRIPTOR 'input_params';`
`EXEC SQL GET DESCRIPTOR 'input_params'`
`:n = COUNT;`
`for (i = 1; i < n; i++)`
`{`
`EXEC SQL GET DESCRIPTOR 'input_params'`
`VALUE :i,`
`:t = TYPE, ... ;`
`EXEC SQL SET DESCRIPTOR 'input_params'`
`VALUE :i`
`DATA = :d, INDICATOR = :ind;`
`}`
`EXEC SQL EXECUTE stmt`
`USING SQL DESCRIPTOR 'input_params';`
- Implicit conversions from database to descriptor area (and vice versa) and from descriptor area to application program (and vice versa)
- Descriptor area can be used as intermediate location for data

300

▼ Dynamic SQL

- Extended dynamic statement names, cursor names, and descriptor area names may be used when the number of dynamic statements is not known at the time the application is written

```
s = "...";  
s_stmt = "my_stmt";  
s_desc = "my_descriptor";  
s_cursor = "my_cursor";
```

```
EXEC SQL PREPARE :s_stmt FROM :s;  
EXEC SQL ALLOCATE DESCRIPTOR :s_desc;  
EXEC SQL ALLOCATE :s_cursor CURSOR FOR :s_stmt;  
EXEC SQL OPEN :s_cursor;
```

- Extended names
 - ▶ may be LOCAL or GLOBAL (referring to the scope of a module or session)

```
PROCEDURE (... , :s_cursor, ...);
```

```
ALLOCATE GLOBAL :s_cursor CURSOR FOR ...;
```

300

▼ Direct SQL

- Implementation-defined mechanism for executing direct SQL statements
 - ▶ In effect, prepared immediately before execution
 - ▶ Cannot issue dynamic SQL using direct SQL
- Invocation, method of raising error conditions, method of accessing diagnostics information, and the method of returning results are all implementation-defined

302

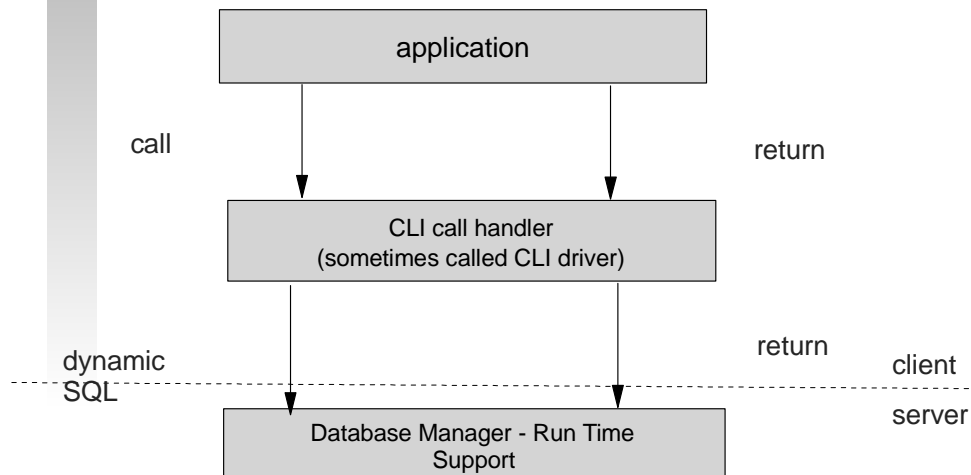
▼ Call Level Interface Overview

- An alternative mechanism for invoking SQL from application programs
 - Similar to dynamic SQL
- Provided for vendors of truly portable "shrink wrapped" software
 - CLI does not require pre-compilation of the application program
 - Application program can be delivered in "shrink wrapped", object-code form
- It is not:
 - Some new way of achieving interoperability
 - An alternative to distributed database protocols such as ISO's RDA
- Based on
 - CLI from SQL Access Group (SAG) and X/Open
 - ODBC (Open DataBase connection)

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▼ Call Level Interface (cont.)

- Functional interface to database
- Consists of over 40 routine specifications
 - Control connections to SQL-servers
 - Allocate and deallocate resources
 - Execute SQL statements
 - Control transaction termination
 - Obtain information about the implementation



304

▼ Call Level Interface

- Uses handles to "manage" resources
 - Environment is the root of all capabilities
 - Other handles exist in the context of an environment
 - Connection handles manage connections to "servers"
 - Statement handles manage SQL statements and cursors
- SQL/CLI behaves much like dynamic SQL
- Uses "CLI Descriptor Area"
 - Analogous to dynamic SQL's system descriptor area, but ...
 - CLI has four descriptors
 - Application parameter descriptor (APD)
 - Application row descriptor (ARD)
 - Implementation parameter descriptor (IPD)
 - Implementation row descriptor (IRD)

305

▼ C Example (page 1)

```
#include "sqlci.h"
#include <string.h>

#ifdef NULL
#define NULL 0

int print_err(HDBC hdbc, HSTMT hstmt);
int example1 (server, uid, pwd)
SQLCHAR *server;
SQLCHAR * uid;
SQLCHAR * pwd;
}
HENV          henv;
HDBC          hdbc;
HSTMT        hstmt;
SQLINTEGER   id;
SQLCHAR      name [51];
SQLINTEGER   namelen;
SQLSMALLINT  scale;
scale = 0
```

306

▼ C Example (page 2)

```
/* connect to database */
/* EXEC SQL CONNECT TO :server USER :uid using :auth_string; */

SQLAllocENV(&henv);           /*allocate an environment handle*/
SQLAllocConnect(henv, &hdbc); /*allocate a connection handle*/
if (SQLConnect(hdbc, server, SQL_NTS, uid, SQL_NTS, pwd, SQL_NTS)
    !=SQL_SUCCESS
    return( print_err(hdbc, SQL_NULL_HSTMT) );
/*create a table*/
/* EXEC SQL CREATE TABLE NAMEID (ID integer, NAME Varchar(50));*/
SQLAllocStmt(hdbc, &hstmt);   /*allocate a statement handle */
}
SQLCHAR create [] = "CREATE TABLE NAMEID (ID integer, NAME varchar(50))";
if SQLExecDirect(hstmt, create, SQL_NTS) != SQL_SUCCESS)
    return(print_err(hdbc, hstmt));
}
/*commit the created table */
/*EXEC SQL COMMIT WORK;*/
SQLEndTran(henv, hdbc, SQL_COMMIT);
```

307

▼ C Example (page 3)

```
/* insert a row into the table */
/*EXEC SQL INSERT INTO NAMEID VALUES (:id, :name );*/
/*EXEC SQL COMMIT WORK ;*/

{
SQLCHAR insert [] = "INSERT INTO NAMEID VALUES (?, ?)";

/*prepare the insert */

if (SQLPrepare(hstmt, insert, SQL_NTS) !=SQL_SUCCESS)
    return(print_err(hdbc, hstmt));
SQLBindParam(hstmt, 1, SQLBUF_LONG, SQL_INTEGER,
    (SQLINTEGER)sizeof(SQLINTEGER), scale, (SQLPOINTER)&id,
    (SQLINTEGER*)NULL);
SQLBindParam(hstmt, 2, SQLBUF_CHAR, SQL_VARCHAR,
    (SQLINTEGER)sizeof(name), scale,
    (SQLPOINTER)name, (SQLINTEGER*)NULL);

/*now assign parameter values and execute the insert*/

id=500
(void)strcpy(name, "Babbage");
if(SQLExecute(hstmt) !=SQL_SUCCESS)
    return(print_err(hdbc, hstmt));
}
SQLEndTran(henv, hdbc, SQL_COMMIT);           /*commit inserts */
```

308

▼ C Example (page 4)

```
/* fetch a row from the table */
/*EXEC SQL DECLARE c1 CURSOR FOR SELECT ID, NAME FROM NAMEID;*/
/*EXEC SQL OPEN c1; */

{
  SQLCHAR Select[] ="select ID, NAME from NAMEID",
  if(SQLExecDirect(hstmt, select, SQL_NTS) !=SQL_SUCCESS)
    return(print_err(hdbc, hstmt));
}
/*EXEC SQL FETCH c1 INTO ;id, :name;*/
/*use column binding */
SQLBindCol(hstmt, 1, SQLBUF_LONG, (SQLPOINTER)&id,
  (SQLINTEGER)sizeof(SQLINTEGER), (SQLINTEGER *)NULL);
SQLBindCol(hstmt,2,SQLBUF_CHAR, (SQLPOINTER)name,
  (SQLINTEGER)sizeof(name), &namelen);

/*now execute the fetch*/
SQLFetch(hstmt);
```

309

▼ C Example (page 5)

```
/* commit, discard hstmt, disconnect*/
/*EXEC SQL COMMIT WORK;*/
/*EXEC SQL CLOSE c1; */
/*EXEC SQL DISCONNECT; */
SQLEndTran(henv, hdbc, SQL_COMMIT); /*commit the transaction */
SQLFreeStmt(hstmt, SQL_DROP); /* free the statement handle*/
SQLDisconnect(hdbc) /*disconnect from the database*/
SQLFreeConnect(hdbc) /* free the connection handle*/
SQLFreeEnv(henv) /*free the environment handel*/
return(0);
}
```

310



New CLI99 Features

- **SQL99 data type support**
 - ▶ BOOLEAN
 - ▶ LOBs with optional locators and helper routines (GetLength, GetPosition, GetSubstr)
 - ▶ UDTs with locators and transformation functions
 - ▶ Arrays with locators only
 - ▶ Reference types with table scope
 - ▶ Can retrieve/store unnamed ROW types

311




New CLI99 Features

- CLI descriptor model aligned with ODBC 3.x (defaults, Get/Set restrictions, etc.)
- JDBC 2.0 support for user-defined types
- Multi-row fetch a la ODBC
- Catalog routines aligned with SQL99 and ODBC
- Parallel result set processing after CALL statement
- SQL99 savepoints
- General SQL99 alignment (roles, user-defined casts, SQLSTATEs, etc.)

312

▼ Conformance

- SQL-92 used incremental levels of conformance (Entry, Intermediate, Full)
- SQL99 consists of a large number of small "features", each identified and precisely specified as to its content
- Each feature is specified either to be a constituent of "Core SQL", or not a constituent of Core SQL 
- A non-core feature might be specified as a constituent of one of the named and defined "Packages", each of which require conformance to Core.

313

▼ Overview of SQL99 Core Features



- All of SQL-92 Entry level
- Some Transitional SQL-92 features
- Some Intermediate SQL-92 features
- Some Full SQL-92 features
- The following new features of SQL3
 - ▶ Distinct data types, including USER_DEFINED_TYPES view
 - ▶ WITH HOLD cursors
 - ▶ SQL-invoked routines, but not the ability to explicitly specify a PATH:
 - CALL statement (with the extension to dynamic SQL to support CALL)
 - RETURN statement
 - ROUTINES and PARAMETERS view
 - SQL-invoked routines written in both SQL and an external language (one can conform by supporting only one)
 - ▶ Value expression in order by clause

314

Core SQL99 Features



- Numeric data types
 - All spellings of INTEGER and SMALLINT
 - REAL, DOUBLE PRECISION, FLOAT
 - DECIMAL and NUMERIC
 - Arithmetic operators
 - Numeric comparison
 - Implicit casting among numeric data types
- Character data types
 - CHARACTER (all spellings)
 - CHARACTER VARYING (all spellings)
 - Character literals
 - Functions
 - CHARACTER_LENGTH
 - OCTET_LENGTH
 - SUBSTRING
 - UPPER
 - LOWER
 - TRIM
 - POSITION
 - Character concatenation
 - Implicit casting among character data types
 - Character comparison
- Identifiers
 - Delimited identifiers
 - Lower case identifiers
 - Trailing underscore
- Basic query specification
 - SELECT distinct
 - GROUP BY clause
 - GROUP BY with columns not in column list
 - AS clause
 - HAVING clause
 - Qualified * in select list
 - Correlation names in FROM
 - AS in FROM clause (rename columns)
- Basic predicates and search conditions
 - Comparison predicate
 - BETWEEN predicate
 - IN predicate with list of values
 - LIKE predicate
 - LIKE predicate with ESCAPE clause
 - NULL predicate
 - Quantified comparison predicate
 - EXISTS predicate
 - Subqueries in comparison predicate
 - Subqueries in IN predicate
 - Subqueries in quantified comparison predicate
 - Correlated subqueries
 - Search condition
- Basic query expressions
 - UNION ALL
 - EXCEPT DISTINCT
 - Columns combined via UNION and EXCEPT do not have to be exact same data types
 - Table subquery can specify UNION and EXCEPT

315

Core SQL (cont.)



- Basic privileges
 - SELECT, DELETE
 - INSERT at table level
 - UPDATE at table and column levels
 - REFERENCES at table and column levels
 - WITH GRANT OPTION
- SET functions
 - AVG, COUNT, MAX, MIN, SUM
 - ALL and DISTINCT quantifiers
- Basic data manipulation
 - INSERT statement
 - Searched UPDATE, DELETE
 - Single-row SELECT statements
- Basic cursor support
 - DECLARE CURSOR
 - ORDER BY columns need not be in SELECT list
 - Value expressions in ORDER BY clause
 - OPEN, CLOSE, FETCH (implicit NEXT)
 - Positioned UPDATE and DELETE
 - WITH HOLD cursors
- Null value support
- Basic integrity constraints
 - NOT NULL constraints
 - UNIQUE constraints of NOT NULL columns
 - PRIMARY KEY constraints
 - Basic FOREIGN KEY constraints with the NO ACTION default for both referential delete and referential update action
 - CHECK constraints
 - Column defaults
 - NOT NULL inferred on PRIMARY KEY
 - Names in a foreign key can be specified in any order
- Transaction support
 - COMMIT and ROLLBACK
- Basic SET TRANSACTION statement
 - with ISOLATION LEVEL SERIALIZABLE clause
 - with READ ONLY and READ WRITE clauses
 - with DIAGNOSTIC SIZE clause
- Updateable queries with subqueries
- SQL comments using leading double minus
- SQLSTATE support
- Module language (at least one binding to a standard host language using either module language, embedded SQL, or both)
- Basic information schema views
 - COLUMNS, TABLES, VIEWS, TABLE_CONSTRAINTS, REFERENTIAL_CONSTRAINTS, CHECK_CONSTRAINTS

316

Core SQL (cont.)



- Basic schema manipulation
 - CREATE TABLE for persistent base tables
 - CREATE VIEW
 - GRANT
 - ALTER TABLE ADD COLUMN
 - DROP TABLE, DROP VIEW, and REVOKE, all with RESTRICT clause
- Basic joined table
 - Inner join (but not necessarily INNER keyword)
 - LEFT and RIGHT OUTER JOIN
 - Nested outer joins
 - The inner table in a left or right outer join can also be used in an inner join
 - All comparison operators are supported
- Basic date and time
 - DATE data type and DATE literal
 - TIME data type with fractional seconds precision of at least 0 (also literal)
 - TIMESTAMP data type (and literal) with fractional seconds precision of at least 0 and 6
 - Comparison predicate on DATE, TIME, and TIMESTAMP data types
 - Explicit CAST between datetime types and character types
- CURRENT_DATE, LOCALTIME, and LOCALTIMESTAMP functions
- UNION and EXCEPT in views
- Grouped operations
 - Multiple tables supported in queries with grouped views
 - Set functions supported in queries with grouped views
 - Subqueries with GROUP BY and HAVING clauses and grouped views
 - Single row SELECT with GROUP BY and HAVING clauses and grouped views
- The ability to associate multiple host compilation units with a single SQL-session at one time
- CAST function where relevant for all supported data types
- Explicit defaults including its use in UPDATE and INSERT statements
- CASE expressions
 - Simple and searched
 - NULLIF
 - COALESCE
- Schema definition statement
 - CREATE SCHEMA
 - CREATE TABLE for persistent base tables
 - CREATE VIEW
 - CREATE VIEW: WITH CHECK OPTION
 - GRANT statemtn
- Scalar subquery values
- Expanded NULL predicate (the <row value expression> can be something other than a <column reference>)

317

Core SQL (cont.)



- Features and conformance views
 - SQL_FEATURES, SQL_SIZING, and SQL_LANGUAGE views
- Basic flagging
 - Core SQL level
 - Syntax Only extent
- Distinct data types
 - USER_DEFINED_TYPES view
- Basic SQL-invoked routines
 - "Routine" is the collective term for functions, methods, and procedures
 - Overloading for functions and procedures is not part of Core
 - Function invocation
 - CALL and RETURN statements
 - ROUTINES and PARAMETERS views

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▼ Packages

PKG001	Enhanced Datetime Facilities
PKG002	Enhanced Integrity Management
PKG003	OLAP Features
PKG004	PSM (i.e., Part 4)
PKG005	CLI (i.e., Part 3)
PKG006	Basic Object Support
PKG007	Enhanced Object Support
PKG008	Active Database (Triggers - row-level only)
PKG009	SQL/MM Support

Others might be defined, not necessarily in the SQL standard itself.

319

▼ PKG001 - Enhanced DATETIME Facilities

- Intervals and datetime arithmetic
- Time zones
- Enhanced seconds precision (sub-microsecond)

320

PKG002 - Enhanced Integrity Management

ON DELETE

ON UPDATE ...

CREATE ASSERTION

- Constraint Management
via constraint names
- Subqueries in CHECK constraints
- Triggers
row-level and statement-level

321

PKG003 - OLAP Facilities

CUBE, ROLLUP

INTERSECT, EXCEPT ALL

FULL JOIN

- Derived tables in the FROM clause
- More than one row in VALUES

322

PKG006 - Basic Object Support

- Structured types with restrictions on use
- Reference types, with restrictions
- Typed base tables
- Predicate to test most specific type of a value
- Basic LOB support including locators

323

PKG007 - Enhanced Object Support

- ALTER TYPE
- Static methods
- Structured types without restrictions
- Reference types without restrictions
- Schema paths
- Subtables
- TREAT
- User-defined casts and transforms
- Locators for structured type values

324

▼ **PKG009 - SQL/MM Support**

- Structured types without restriction
- Arrays/incl. arrays of structured types
- User-defined cast
- Overloading (routines with same name in same schema)

325

▼ **SQL/MM Motivation**

- Enabling functionality
- SQL3 provides ...
 - ▶ Definition of user-defined, application specific data types
 - ▶ Implementation of user-defined functions to support application specific operations on the data types
 - ▶ Storage of large objects (BLOBs and CLOBs)
 - ▶ Powerful trigger and constraint mechanisms to maintain the integrity and semantics of the new data types
 - ▶ Storage and execution of user-defined stored procedures in the server
- This enables ...
 - ▶ Development of application specific collections of user-defined types, user-defined functions, triggers, constraints, and stored procedures (i.e. libraries) "tight" to the DBMS engine

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▼ SQLMM Overview

Multipart standard:

- **SQL/MM Framework** (Part 1)
 - Overview and conformance
- **SQL/MM Full-text** (Part 2)
 - Information about construction of text and search patterns, and for the searching of text
- **SQL/MM Spatial** (Part 3)
 - Information about storing, managing, and retrieving information related to spatial data such as geometry and topography
- **SQL/MM Still-image** (Part 5)
 - Information about searching large collections of still images

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▼ SQL/MM Full-Text

- **Why Full-Text standard library?**
 - Built-in search facilities (LIKE, SIMILAR) not powerful enough (text viewed as string of characters).
 - Need higher level notion of text
- **Structural units in Full-Text:**
 - Words
 - Sentences
 - Paragraphs
- **Operations in Full-Text:**
 - Boolean Search
 - Ranking
 - Conceptual Search

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SQL/MM Full-Text: Boolean Search

- Full-Text sample:
Every text value is associated with a specific language.
- Full-Text items have language attribute
- Boolean query facilities
 - Single word search
 - Phrase search
 - Context based search
 - Linguistic search
 - Stopword processing
 - Masking facilities
 - Search pattern expansion, e.g.:
 - Sound expansion
 - Broader/narrower term expansion
 - Synonym expansion

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SQL/MM Full-Text: Boolean search examples

- Single word search:

```
SELECT * FROM myDocs
WHERE 1 = CONTAINS(TextBody, "specific")
```

every text value is associated with a specific language.
- Phrase search:

```
SELECT * FROM myDocs WHERE 1 =
WHERE 1 = CONTAINS(TextBody, "specific language")
```

every text value is associated with a specific language.
- Context search:

```
SELECT * FROM myDocs WHERE 1 = CONTAINS(TextBody,
"text IN SAME SENTENCE AS language")
```

every text value is associated with a specific language.
- Stopwords:

```
SELECT * FROM myDocs WHERE CONTAINS(TextBody,
"value was associated")
```

every text value is associated with a specific language.
- Linguistic search:

```
SELECT * FROM myDocs WHERE CONTAINS(TextBody,
'STEMMED FORM OF "values are associated"')
```

every text value is associated with a specific language.

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▼ SQL/MM Full-Text

- Ranking

```
SELECT * FROM myDocs  
WHERE 1.2 < RANK(TextBody, 'specific')
```

- ▶ Ranks according to implementation - defined criteria (e.g. frequency of "specific")

- Conceptual search

```
SELECT * FROM myDocs  
WHERE 1 = CONTAINS(TextBody,  
'IS ABOUT "every text value is associated  
with a specific language"')
```

- ▶ Identifies Full-Text items which are pertinent to rhs of "IS ABOUT" operator

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▼ SQL/MM Spatial: Goals, Motivation

- Goals

- ▶ Support for "flat world" (2-d) geometric objects and operations
- ▶ Coverage of important application areas
- ▶ Simple features

- Motivation

- ▶ Breaking ground for **standard** type library
- ▶ Promote efficient access methods on relational platforms

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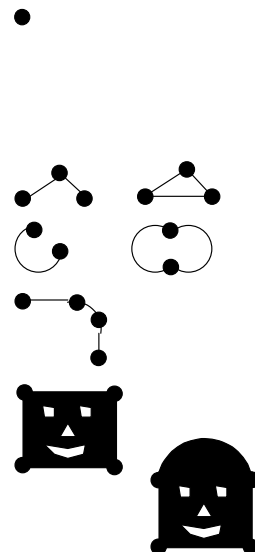
SQL/MM Spatial: Players

- JTC1 SC32 WG4: SQL/MM Spatial
- ISO TC211: Geomatics
- Open GIS Consortium:
 - OpenGIS Simple Feature Specification
 - SQL2 Bindings
 - CORBA Binding
 - OLE Binding
 - SQL3 Bindings: SQL/MM Spatial
 - Guarantees implementations
 - Established verification procedures

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Spatial Objects

- 0-dim. objects: points
- 1-dim. objects: (planar) curves; sub- types differ by interpolation betw. points
 - ST_LineString: linear interpolation
 - ST_CircularString (opt): circular arcs
 - ST_CompoundString (opt): mixed
- 2-dim. objects: (planar) surfaces
 - ST_Polygon: ST_LineString boundaries
 - ST_CurvePolygon (opt): ST_CompoundString boundaries



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▼ Spatial Objects (cont.)

■ Collection valued objects:

ST_Geometry

- ▶ Reference system: same for all elements
- ▶ Any geometry type admissible
- ▶ Subtypes of ST_Geometry with restrictions on element types

- ST_MultiPoint



- ST_MultiCurve



- ST_MultiPolygon



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▼ SQL/MM Spatial: Operations

■ Usual observers and mutators

■ Transform routines

- ▶ Transform objects into binary or textual representations (and vice versa)
- ▶ Enables implementation by 3GL functions using minimal SQL3 machinery

■ Important topical operations, e.g.

- ▶ Constructors (controlling wellformedness)
- ▶ Distance
- ▶ Tests (contains, overlaps, touches, crosses, ...)
- ▶ Intersection, difference, union
- ▶ Find referencing system
- ▶ Length, area, perimeter

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SQL/MM Spatial: Example

```
SELECT * FROM stores s, customers c
WHERE within(c.loc, s.zone)
      or distance(c.loc, s.loc)<100
ORDER BY s.name, c.name;
```

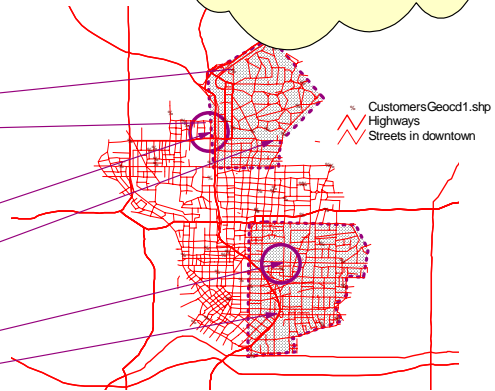
"Tell me all the information I have about each customer who either lives within a stores' zone or within 100 miles of the store."

CUSTOMERS

CID	NAME	INCOME	ADDR	LOC

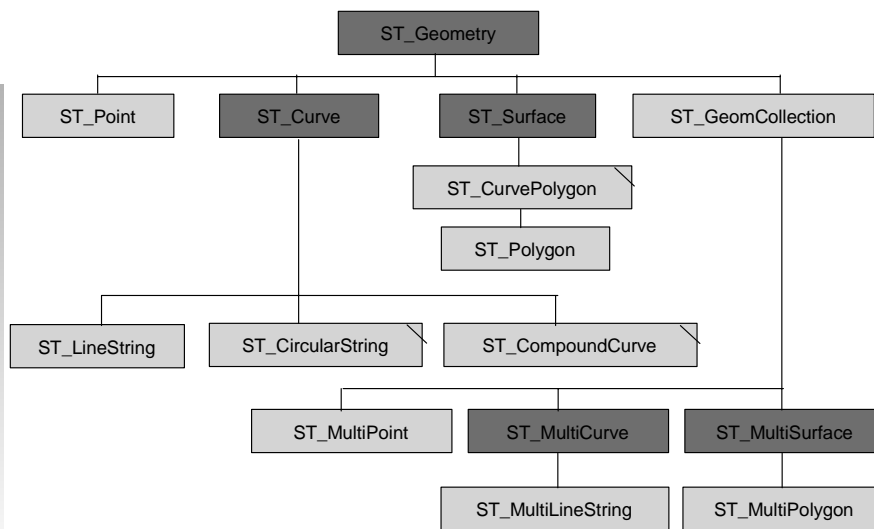
STORES

SID	NAME	ADDR	LOC	ZONE



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SQL/MM Spatial: Type Hierarchy



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▼ Spatial Reference System

- Controls aspects like units, prime meridian, coordinate system etc.
- Relies on reference systems defined by other authorities.
- Defined representation of reference system values
- One common spatial reference system value:
 - For elements of ST_Geometry values
 - Within column of type ST_Geometry

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▼ SQL/MM Still-Image: Goals

- Enable screening of large imagebases
- Support for proven set of image features
- Type structure adaptable to evolving image processing technology
- Example: Find all possibly infringed logos by scoring them against a new logo.

```
SELECT * FROM RegLogos  
WHERE 1.2 <  
SI_findTexture(newLogo).SI_Score(Logo)
```

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▼ SQL/MM Still-Image Objects

- SI_StillImage: raster images
- Abstract SI_Feature with subtypes
 - SI_AverageColor
 - SI_ColorHistogram
 - SI_PositionalColor: average colors of n*m image segments
 - SI_Texture: coarseness, contrast, directionality
- SI_FeatureList: weighted list of SI_Feature items

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▼ SI_StillImage: Operations

- Constructor function
- Observer Methods for
 - Raw picture data
 - Image format (e.g. JPEG)
 - Pixel properties (bits per color, per pixel)
 - Size ..
 - Generation time, last update time
- Mutator for (raw) image content

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▼ SI_Feature, SI_FeatureList: Operations

- All: scoring method (SI_Score)
 - Scores image w.r.t. a given feature
- All subtypes of SI_Feature
 - function extracting feature from images
- SI_AverageColor, SI_ColorHistogram
 - function for "manual" feature construction
- SI_FeatureList: feature/weight pairs lists
 - Constructor function for list header
 - Append method to extend feature list by another feature/weight pair

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▼ SQL/MM Still-Image: Final Example

- Screen all logos in table RegLogos against a given logo (newLogo); use the texture and average colors of a standard grid of image segments ("positional color") for scoring; give these features of newLogo the weights 80% and 20%, resp.

```
SELECT * FROM RegLogos
WHERE 1.2 <
  SI_InitFeatureList
    (SI_findTexture(newLogo), 0.8).SI_Append
    (SI_findPositionalColor(newLogo), 0.2)
  .SI_Score(Logo)
```

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SQLJ

- SQLJ Part 0
 - ▶ Embedded SQL in Java
 - ▶ Currently based on SQL-92, JDBC 1.2
 - ▶ Accepted ANSI standard "Database Language - SQL, Part 10 Object Language Bindings (SQL/OLB)", ANSI X3.135.10:1998
 - ▶ Currently being processed by ISO, (SQL-99 alignment)
- SQLJ Part 1
 - ▶ Java static methods as SQL UDFs and stored procedures SQL routines (stored procedures, user-defined functions)
 - ▶ Currently a working draft, being prepared for submission to ANSI
- SQLJ Part 2
 - ▶ Use of Java classes to define SQL types
- Potential for wide DBMS vendor acceptance
 - ▶ Cloudscape, Compaq (Tandem), IBM, Informix, MicroFocus, Oracle, Sun, Sybase
- Tremendous possibilities
 - ▶ Baan, PeopleSoft, SAP exploitation?
 - ▶ the "next ODBC"?

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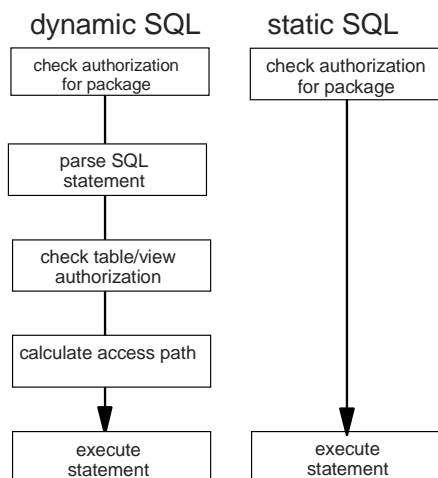
SQLJ Part 0: Overview

■ Static SQL syntax for Java

- ▶ INSERT, UPDATE, DELETE, CREATE, GRANT, etc.
- ▶ Singleton SELECT and cursor-based SELECT
- ▶ Calls to stored procedures (including result sets)
- ▶ COMMIT, ROLLBACK
- ▶ Methods for CONNECT, DISCONNECT

■ Similar tradeoffs

- Static vs. dynamic
- SQLJ vs. JDBC
- ▶ Less flexible at run-time
- ▶ Allows error checking at development time
- ▶ Static SQL is faster!!!



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▼ SQLJ Part 0: Overview (cont.)

- Static SQL authorization
 - Static SQL is associated with "program"
 - Plans/packages identify "programs" to DB
 - Program author's table privileges are used
 - Users are granted EXECUTE on program
 - Dynamic SQL is associated with "user"
 - No notion of "program"
 - End users must have table privileges
 - BIG PROBLEM FOR A LARGE ENTERPRISE !!!
- SQLJ programs are smaller than JDBC applications
- Can be used in client code and stored procedures
 - Easier than JDBC, better performance too!
- Binary portability

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▼ SQLJ Syntax

- SQLJ clauses are statements or declarations
 - Clause begins with "#sql" token
- An SQL statement appears as an SQLJ statement clause
 - May contain host-variable references (e.g., :x) or host expressions (e.g., :(x + y))
 - Can span multiple lines
 - May specify explicit connection or use default connection

```
#sql [ [<context>] ] { <statement spec clause> }
```

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SQLJ vs. JDBC: Retrieve Single Row

■ SQLJ

```
#sql [con] { SELECT ADDRESS INTO :addr FROM EMP  
WHERE NAME=:name };
```

■ JDBC

```
java.sql.PreparedStatement ps =  
con.prepareStatement("SELECT ADDRESS FROM EMP  
WHERE NAME=?");  
ps.setString(1, name);  
java.sql.ResultSet names = ps.executeQuery();  
names.next();  
name = names.getString(1);  
names.close();
```

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SQLJ vs. JDBC: Insert One Row

■ SQLJ

```
#sql [con] {INSERT INTO T1 VALUES( :hv1, :hv2, :hv3 )};
```

■ JDBC

```
CallableStatement mystmt =  
con.prepareCall("INSERT INTO T1 VALUES(?,?,?)");  
mystmt.setString(1,hv1);  
mystmt.setString(2,hv2);  
mystmt.setInt(3,hv3);  
mystmt.executeUpdate();
```

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SQLJ vs. JDBC: Call Stored Procedure

■ SQLJ

```
#sql [con] {CALL PROC1(:IN hv1, :OUT hv2) };
```

■ JDBC

```
CallableStatement mystmt =  
    con.prepareCall("CALL PROC1(?,?)");  
mystmt.setString(1,hv1);  
mystmt.registerOutParameter(2, java.sql.Types.VARCHAR);  
mystmt.executeUpdate();  
hv2 = mystmt.getString(2);
```

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Result Set Iterators

- Mechanism for accessing the rows returned by a query
 - Comparable to an SQL cursor
- SQLJ Iterator declaration clause results in generated iterator class
 - Iterator is a Java object
 - Iterators are strongly typed
 - Generic methods for advancing to next row
- SQLJ assignment clause assigns query result to iterator
- Two types of iterators
 - Named iterator
 - Psitioned iterator

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▼ Named Iterator

- Generated iterator class has accessor methods for each result column

```
#sql iterator Honors ( String name, float grade );
Honors honor;
#sql [recs] honor =
  { SELECT SCORE AS "grade", STUDENT AS "name"
    FROM GRADE_REPORTS
    WHERE SCORE >= :limit AND ATTENDED >= :days AND
      DEMERITS <= :offences
    ORDER BY SCORE DESCENDING };
while (honor.next()) {
  System.out.println( honor.name() + " has grade "
    + honor.grade() );
}
```

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▼ Positioned Iterator

- Use FETCH statement to retrieve result columns into host variables based on position

```
#sql iterator Honors ( String, float );
Honors honor;
String name;
float grade;
#sql [recs] honor =
  { SELECT STUDENT, SCORE FROM GRADE_REPORTS
    WHERE SCORE >= :limit AND ATTENDED >= :days AND
      DEMERITS <= :offences
    ORDER BY SCORE DESCENDING };
while (true) {
  #sql {FETCH :honor INTO :name, :grade };
  if (honor.endFetch()) break;
  System.out.println( name + " has grade " + grade );
}
```

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▼ Connection Contexts

- Used to associate execution of SQL statements with a database connection
- Explicit connection context
 - Declare connection context class
`#sql context DB1con;`
 - Create connection context object
`String url = "jdbc:.....";`
`DB1con con = new DB1con(url, "user", "password", false);`
 - Use connection context in SQLJ statement clause
`#sql [con] {SELECT c INTO :x FROM mytable};`
- Default connection context
 - Used if no explicit connection context is specified in SQLJ clause
 - Important usage: stored procedures written in SQLJ
 - Default context provided by database environment
- Application can use multiple connections to the same or different databases at the same time
- Connections can be shared across threads in a multi-threaded application

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▼ Execution Contexts

- Describes execution semantics of SQL operations
 - Control execution environment
 - MaxRows, MaxFieldSize, QueryTimeout
 - Get description of results of SQL statement execution
 - UpdateCount, SQLWarnings
- Example
 - Create new execution context
`ExecutionContext exec = new ExecutionContext();`
 - Set execution context attribute
`exec.setQueryTimeout(3); // wait only 3 seconds`
 - Use execution context in SQLJ statement clause
`#sql [con, exec] { DELETE FROM mytable WHERE ...};`
 - Get execution information
`System.out.println`
`("deleted " + exec.getUpdateCount() + " rows");`

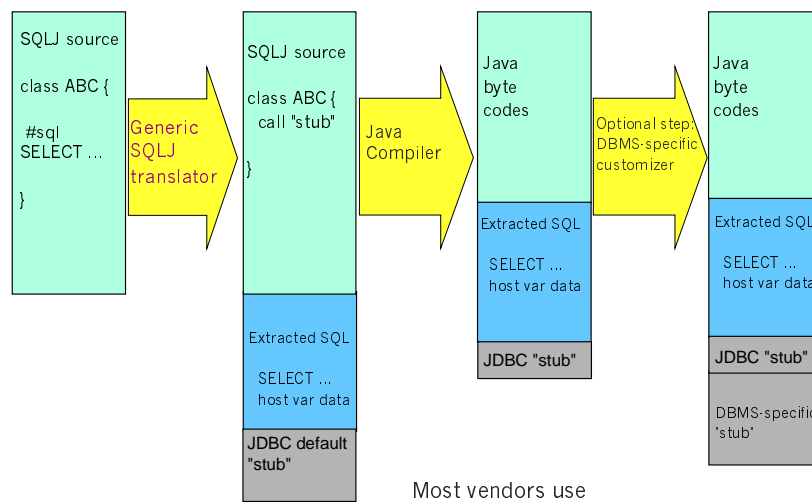
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Advanced Features

- Multiple result sets from stored procedures
 - Side-channel result sets
 - Use method "getNextResultSet" on execution context to navigate through results
- SQLJ and JDBC interoperability
 - Mixing SQLJ (static SQL) and JDBC (dynamic SQL) in the same application
 - SQLJ and JDBC can share the same connections
 - JDBC result sets can be turned into SQLJ iterators, and vice versa

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Compiling an SQLJ Application



Most vendors use default JDBC "stub"

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▼ Binary Portability

- Static SQL portability problems
 - 3GL language not 100% portable
 - Each DBMS has unique precompiler output
 - No binary portability across DBMSs
- SQLJ advantages
 - Java is platform-independent
 - Compiled SQLJ applications are pure Java
 - Generic SQLJ translator (works for all DBMSs)
 - SQLJ application binaries (Java bytecodes) are portable across DBMSs
 - Vendor-specific customizations can be performed after compilation
 - Performance optimizations, ...

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▼ SQLJ Part 1: Overview

- Java static methods as SQL UDFs and stored procedures
 - Can contain JDBC or SQLJ calls
- Many advantages
 - Processing power on database server
 - Reduce volume of data transfer by sending final answer sets
 - Centralize the administration of the business logic
 - Access operations not available on client/gateway tier
 - Direct use of pre-written Java libraries
 - Portable across DBMSs and platforms
 - Deployable across different tiers
- Invocation
 - Can be called by any Java or non-Java client code
 - DBMS invokes the JVM to run the Java application
 - DBMS handles type conversions between Java and SQL

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▼ Installing Java Classes in the DB

■ Installation

- ▶ New install_jar procedure
`sqlj.install_jar ('file:~/classes/routines.jar', 'routines_jar')`
- ▶ Parameters: URL of JAR file with Java class and string to identify the JAR in SQL
- ▶ Install all classes in the JAR file
- ▶ Uses Java reflection to determine names, methods, signatures
- ▶ Optionally uses deployment descriptor file found in JAR to create SQL routines

■ Removal

- ▶ `sqlj.remove_jar ('routines_jar')`

■ Replacement

- ▶ `sqlj.replace_jar ('file:~/classes/routines.jar', 'routines_jar')`



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▼ Creating Procedures and UDFs

`sqlj.install_jar ('file:~/classes/routines.jar', 'routines_jar')`

*Java return type 'void' -> stored procedure
otherwise -> user-defined function*

```
CREATE PROCEDURE modify_address (ssn INTEGER, addr CHAR (40))  
MODIFIES SQL DATA  
EXTERNAL NAME 'routines_jar:addr.modifyaddr'  
LANGUAGE JAVA  
PARAMETER STYLE JAVA
```

```
CREATE FUNCTION zip (addr CHAR (40)) RETURNS INTEGER  
NO SQL  
DETERMINISTIC  
EXTERNAL NAME 'routines_jar:addr.zip'  
LANGUAGE JAVA  
PARAMETER STYLE JAVA
```

routines.jar

```
public class addr{  
public static void  
modifyaddr (...)  
public static  
integer  
zip (string s) ...
```

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▼ Invoking SQLJ Routines

■ Privileges

- ▶ Usage privilege on installed JAR file is grantable
`GRANT USAGE ON JAR routines_jar TO bryan`
- ▶ Execute privilege on routines is grantable
`GRANT EXECUTE ON modify_address TO bryan`
`GRANT EXECUTE ON zip TO bryan`

■ Invocation

- ▶ User-defined function
`SELECT zip (home_addr) FROM employees`
- ▶ Stored procedure
`CALL modify_address (64148342, '1664 Tunis Rd, San Bruno, CA')`

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▼ SQLJ Stored Procedures

■ OUT and INOUT parameters

- ▶ `CREATE PROCEDURE`
`avgSal (IN dept VARCHAR(30), OUT avg DECIMAL(10, 2))`
...
- ▶ Java method declares them as arrays
- ▶ Array acts as container that can be filled/replaced by the method implementation to return a value
- ▶ `public static void averageSalary (String dept, BigDecimal[] avg) ...`

■ Returning result set(s)

- ▶ `CREATE PROCEDURE ranked_emps (region INTEGER)`
`DYNAMIC RESULT SETS 1 ...`
- ▶ Java method declares explicit parameters for returned result sets of type
 - array of (JDBC) ResultSet
 - array of (SQLJ) iterator class, prev. declared in "#sql iterator ..."
 - `public static void ranked_emps (int region, ResultSet[] rs) ...`
- ▶ Java method body assigns (open) result sets as array elements of result set parameters
- ▶ Multiple result sets can be returned

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▼ Error Handling

- Java method throws an SQLException to indicate error to the SQL engine
 - ... throws new SQLException ("Invalid input parameter", "38001");
 - SQLSTATE value provided has to be in the "38xxx" range
- Any other uncaught Java exception is turned into a SQLException "Uncaught Java exception" with SQLSTATE "38000" by the SQL engine
- Java exceptions that are caught within an SQLJ routine are internal and do not affect SQL processing

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▼ Additional Features

- Java "main" methods
 - Java signature has to have single parameter of type String[]
 - Corresponding SQL routine has
 - Either 0 or more CHAR/VARCHAR parameters,
 - or a single parameter of type array of CHAR/VARCHAR
- NULL value treatment
 - Use Java object types as parameters (see JDBC)
 - SQL NULL turned into Java null
 - Specify SQL routine to return NULL if an input parameter is NULL
 - `CREATE FUNCTION foo(integer p) RETURNS INTEGER RETURNS NULL ON NULL INPUT`
 - Otherwise run-time exception will be thrown
- Static Java variables
 - Can be read inside SQL routine
 - Should not be modified (result is implementation-defined)
- Overloading
 - SQL rules may be more restrictive
 - Map Java methods with same name to different SQL routine names

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▼ Conformance

- For SQLJ Part 1 Core compliance, a lot of features are optional, such as
 - DDL vs. deploy/undeploy descriptors in SQLJ JAR files
 - Either DDL or descriptors for CREATE PROCEDURE/FUNCTION has to be supported
 - SQLJ Paths
 - INOUT, OUT parameters for stored procedures
 - support for returning result sets in stored procedures
 - SQL array datatype for support Java 'main' arguments
 - GRANT statement, WITH GRANT OPTION
 - REVOKE statement

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▼ JDBC 2.0 Extensions for SQL99 Types

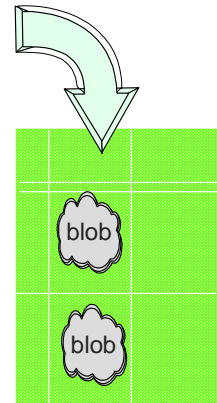
- Added support for object-relational data types
 - User-defined types (UDTs)
 - Structured types
 - Distinct types
 - References
 - Arrays (collection types)
- Supports mappings of DB structured types to/from Java classes
 - Focus on **object state**, not on interface (behavior)
 - Provides sufficient basis for mapping tools
 - Allows application to provide mapping information to JDBC driver
- Capabilities for handling LOBs
 - Work with character LOBs and binary LOBs
 - LOB locator support

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▼ "Native" Java Object Support

- "Native" Java Objects in the database as "BLOBs"
 - Based on Java Serialization
- Support built into the JVM
- Too restrictive
 - persistence for Java objects
 - DB sees Java object as a black-box
 - Based on Java type system, not SQL
 - Object state cannot be introspected at the DB server side
 - Private attributes
 - Not usable for row objects/typed tables
 - Client applications written in other progr. language not supported
 - Performance implications
 - DB attribute accessors and functions/methods need to de-serialize the Java object state for execution

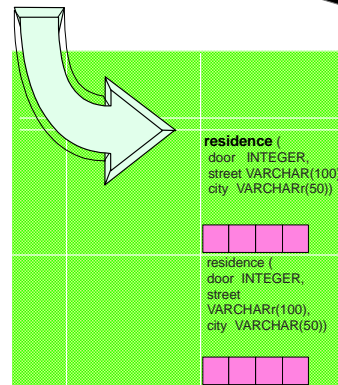
```
public class Residence {
    public int door;
    public String street;
    public String city;
}
```



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▼ Mapping Java Objects to Structured Types

- Support built into the DBMS
- Very flexible
 - DB understands internal structure of type
 - Based on SQL type system
 - Client applications written in other programming languages are supported
 - Can be used to define row types/typed tables
 - DB functions/methods can be implemented in other programming language
- Potential for better performance
- Requires conversion (Java <-> SQL)



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▼ JDBC 2.0 Structured Type Support

- Materializing SQL99 types as Java objects
 - ▶ SQL99 types manipulated using existing result set or prepared statement interfaces
 - ▶ **get/setObject(<column>)** simply "works" for structured types

▶ Example:

```
ResultSet rs = stmt.executeQuery(
    "SELECT e.addr FROM Employee e");
rs.next( );
Residence addr =
    (Residence)rs.getObject(1);
```

Java

```
public class Residence {
    public int door;
    public String street;
    public String city; }
```



SQL

```
CREATE TYPE residence (
    door      INTEGER,
    street    VARCHAR(100),
    city      VARCHAR(50))
```

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▼ Mapping Infrastructure

- **Mapping table** for recording correspondence of DB UDT and Java class
 - ▶ JDBC driver automatically generates client object, invokes method to 'internalize' state.
 - ▶ Can be attached to a DB connection object
 - ▶ Can be used as additional parameter in get/setObject() calls
- Java class implements interface **SQLData**
 - ▶ readSQL() reads attributes from an SQLInput data stream
 - ▶ writeSQL() writes attributes to an SQLOutput data stream
 - ▶ Ordering of attributes has to be preserved during read/write
 - ▶ Includes handling of nested objects, type conversions, NULL attributes
- **SQLInput, SQLOutput** interfaces
 - ▶ Generic 'stream-based' API for implementing the customized mapping
 - ▶ Used by programmers and mapping tools
 - ▶ Vendor-specific implementation details of object bind-out are hidden

Java

```
public class Residence {
    public int door;
    public String street;
    public String city; }
```



SQL

```
CRATE TYPE residence (
    door      INTEGER,
    street    VARCHAR(100),
    city      VARCHAR(50))
```

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▼ Mapping (Example)

■ Java class

```
public class Residence implements SQLData {
    public int door;
    public String street;
    public String city;
    public void readSQL(SQLInput stream, ...) throws SQLException {
        door = stream.readInt();
        street = stream.readString();
        city = stream.readString(); }
    public void writeSQL(SQLOutput stream, ...) throws SQLException {
        stream.writeInt(door);
        stream.writeString(street);
        stream.writeString(city); } }
```

■ SQL99 type

```
CREATE TYPE residence (
    door INTEGER,
    street VARCHAR(100),
    city VARCHAR(50))
```

■ JDBC driver (SQLJ) automatically generates client object

invokes method to 'internalize' state.Java class

■ Mapping table

records correspondence DB2 type/Java class

■ Server-side SQL99 transformation

defines how UDT is passed to/from the client

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▼ Structured Types: Default Mapping

■ Uses new JDBC interface 'Struct'

- ▶ Struct st = (Struct)resultset.getObject(1)
- ▶ public interface Struct extends SQLData {
 SQLType getSQLType();
 Object[] getAttributes();
}

- ▶ ResultSet.getObject() will now return an object implementing the Struct interface

■ JDBC driver includes a new Java class implementing the Struct interface

■ Generic way of handling a structured object as an array of Java objects that represent the individual attribute values

- ▶ Useful for generic applications/tools

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▼ Object References

- New methods on ResultSet, PreparedStatement
 - `Ref ref = rs.getRef(1);`
- Ref interface
 - Has method for determining the (static) type of the referenced object
 - Hides the underlying data type of the reference
- A Ref object can be used as a parameter in other SQL statements
 - Dereference
 - Path expressions
 - Updates
 - ...

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▼ Manipulating Large Objects

- Existing approach: treat them as LONG VARCHAR, LONG VARBINARY types
- Adding support that allows for LOB locators
 - Introducing type code for BLOB, CLOB
 - Additional methods on ResultSet, PreparedStatement
 - `Blob blob = rs.getBlob(1);`
 - `Clob clob = rs.getClob(2);`
 - Additional interfaces Blob, Clob for manipulating LOB data
 - Operations for piecemeal access to LOB data, finding substrings, etc.
 - Targeted to locator-based implementation as a default
- JDBC permits mechanisms to tell the driver that LOB should be retrieved as locator or as LOB value
 - Vendor-specific extension of JDBC

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▼ Arrays

- Retrieving/storing arrays
 - get/setArray() methods on ResultSet, PreparedStatement
 - Array interface supports methods to:
 - Determine the element type
 - Retrieve an array as a Java array, list of Java objects
 - Open a result set on an array (i.e., turn array into a table)
 - Implementation based on array locators

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▼ SQLJ Part 2: Java Classes as SQL Types

- Use of Java classes to define SQL types
 - Can be mapped to structured types or "native" Java types (blobs)
 - Can be used to define columns in tables
 - Can be used to define SQL99 tables (structured types)
- Mapping of object state and **behavior**
 - Java methods become SQL99 methods on SQL type
 - Java methods can be invoked in SQL statements
- Automatic mapping to Java object on fetch and method invocation
 - Java Serialization
 - JDBC 2.0 SQLData interface
- Includes handling of USAGE privilege on SQL type
- Use the procedures introduced in SQLJ Part 1 to install, remove, and replace SQLJ JAR files

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▼ Mapping Java Classes to SQL

- Described using extended CREATE TYPE syntax
 - DDL statement, or
 - Mapping description in the deployment descriptor
- Supported Mapping

Java	SQL
class	user-defined (structured) type
member variable	attribute
method	method
constructor	initializer method
static method	static method
static variable	static observer method

- SQL initializer methods
 - Have the same name as the type for which they are defined
 - Are invoked using the NEW operator (just like in Java)
- SQL does not know static member variables
 - Mapped to a static SQL method that returns the value of the static variable
 - No support for modifying the static variable

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▼ Mapping Example

■ Java class

```
public class Residence implements SQLData {
    public int door;
    public String street;
    public String city;
    public static String country = "USA";
    public String printAddress() { ...};
    public void changeResidence(String adr) { ... // parse and update fields
...}
}
```

■ SQL DDL/descriptor statement

```
CREATE TYPE Address EXTERNAL NAME 'Residence' language java (
    number INTEGER EXTERNAL NAME 'door',
    street VARCHAR(100),
    city VARCHAR(50),
    STATIC METHOD country( ) RETURNS CHAR(3) EXTERNAL
    VARIABLE NAME 'country',
    METHOD print() RETURNS VARCHAR(200) EXTERNAL NAME
    'printAddress',
    METHOD changeAddress (varchar(200)) RETURNS Address
    SELF AS RESULT EXTERNAL NAME 'changeResidence'
)
```

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▼ Instance Update Methods

- Java and SQL have different object update models
 - Java model is object-based
 - Object method updates object member variables, usually returns void
 - SQL model is value-based
 - Object method returns a modified copy of the object
 - UPDATE statement is required to make object modification permanent
- SQLJ permits mapping without requiring modification of Java methods
 - SELF AS RESULT in deployment descriptor identifies an instance update method
 - Java class

```
public class Residence implements SQLData {  
    ...  
    public void changeResidence(String adr) { ... // parse and update fields ... }  
}
```
 - SQL type

```
CREATE TYPE Address EXTERNAL NAME 'Residence' LANGUAGE JAVA (  
    ...  
    METHOD changeAddress(varchar(200)) RETURNS Address SELF AS RESULT  
    EXTERNAL NAME 'changeResidence'  
)
```
 - At runtime, the SQL system
 - Invokes the original Java method (returning void) on (a copy of) the object
 - Is responsible for returning the modified object

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▼ Usage Examples

- Use type as column type

```
CREATE TABLE employees (  
    name    VARCHAR(40),  
    addr    Address)
```
- Insert object

```
INSERT INTO employees VALUES('John Doe', NEW  
Address( ))
```
- Update object

```
UPDATE employees  
SET addr =  
    addr.changeAddress('1234 Parkway Dr., San Leandro')  
WHERE name = 'John Doe'
```
- Select object information

```
SELECT addr.print( )  
FROM employees  
WHERE addr.city = 'San Leandro'
```

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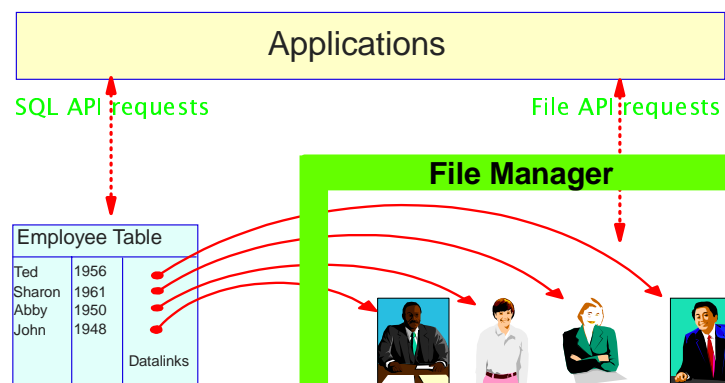
SQL/MED (Management of External Data)

- Still undergoing revisions
- Purpose is to tie SQL with the management of data outside of the database (files)
 - Adds new data type: *datalink*
 - *Link type*
 - *scheme (http or file)*
 - *file server*
 - *file path*
 - *comment*
 - *Abstract LOB type*: used to define routines that are allowed on a LOB
 - *Abstract tables*: Allows for definition of access routines (user-defined routines) such as iterate, update, delete, etc.

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Datalinks

- Helps maintain integrity of links from "database" attributes to data in files.
- The standardized part is datalink data type itself, not the file manager piece.



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▼ SQL/MED

- Abstract tables

- ▶ Lets users write SQL queries on data that is stored in another file system
- ▶ Routines manipulate the data

CREATE ABSTRACT TABLE XRAY

STATE <routine-name>

ITERATE <routine-name>

COMMIT <commit-routine-name>

- Abstract LOBs

- ▶ Like Abstract tables, but for LOBs
- ▶ Routines for locators, concatenation, overlay, substring, etc

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▼ What of the Future? (SQL4)

- OLAP stuff

- ▶ Additional functions, like RANK moving sum, average, ratio, additional aggregation functions
- ▶ Summary tables

- More collection data types

- ▶ set (unordered, no duplicates)
- ▶ list (ordered, may contain duplicates)
- ▶ multiset (unordered, may contain duplicates)

- Type migration

- ▶ How do you make an employee a manager in a table hierarchy?

- ...

In some cases, function is already delivered.
Not the ideal model.

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