Relational (SQL) Database

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Outline

- **Introduction of relational database management system**
- **Relational database design/model**
- **Normalization**
- **On-Line Transaction Processing (OLTP) database system & Structured Query Language (SQL)**
- **Entity-Relationship Model/Diagram & Unified Modeling Language (UML)**
- **On-Line Analytical Processing (OLAP) database**
- **Data warehouse**

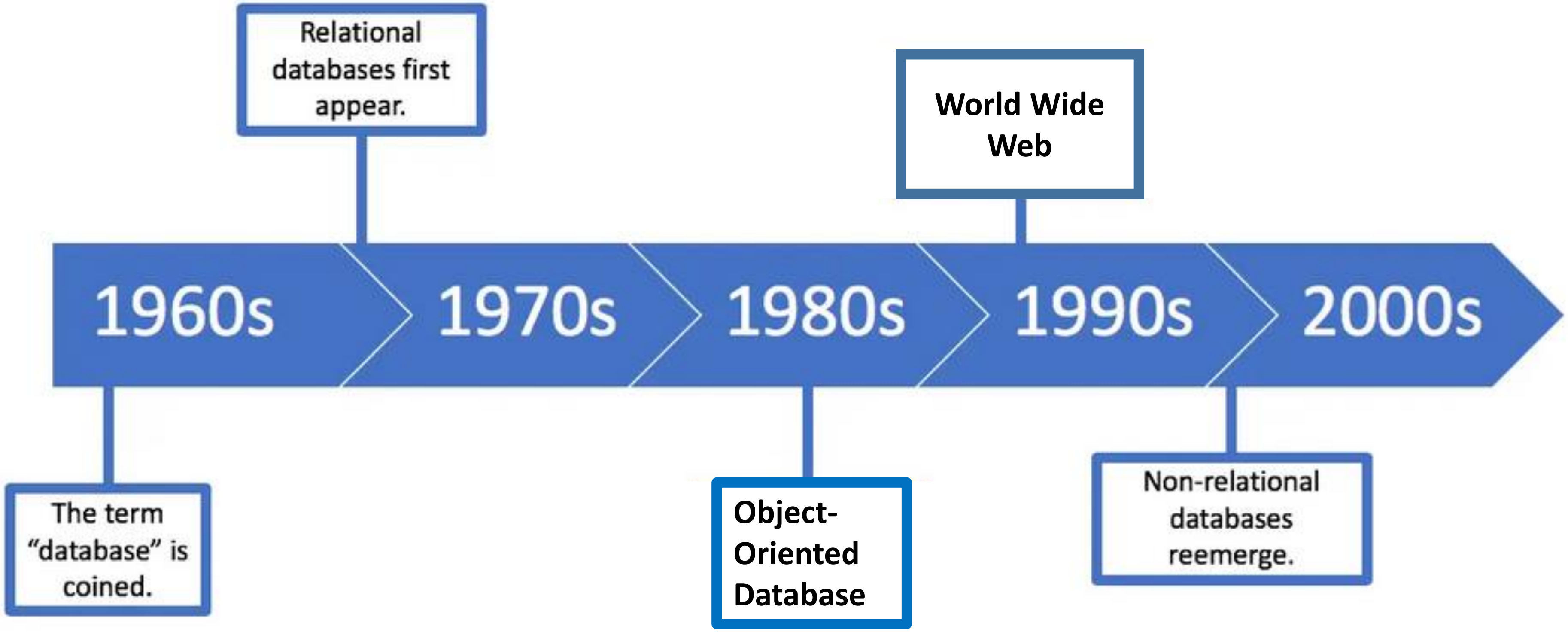
The 4th paradigm: data-intensive scientific discovery

- **It expands the vision of Jim Gray (Mr. Database)**
  - **"The impact of Jim Gray's thinking is continuing to get people to think in a new way about how data and software are redefining what it means to do science."**

    — Bill Gates, Chairman, Microsoft Corporation
- **Data intensive science consists of the following activities:**
  - **Capture**
  - **Management**
  - **Curation**
  - **Analysis**
- **Databases play a key role in supporting the above activities**

Jim Gray: Turing Award receiver in 1998

Timeline for database technologies

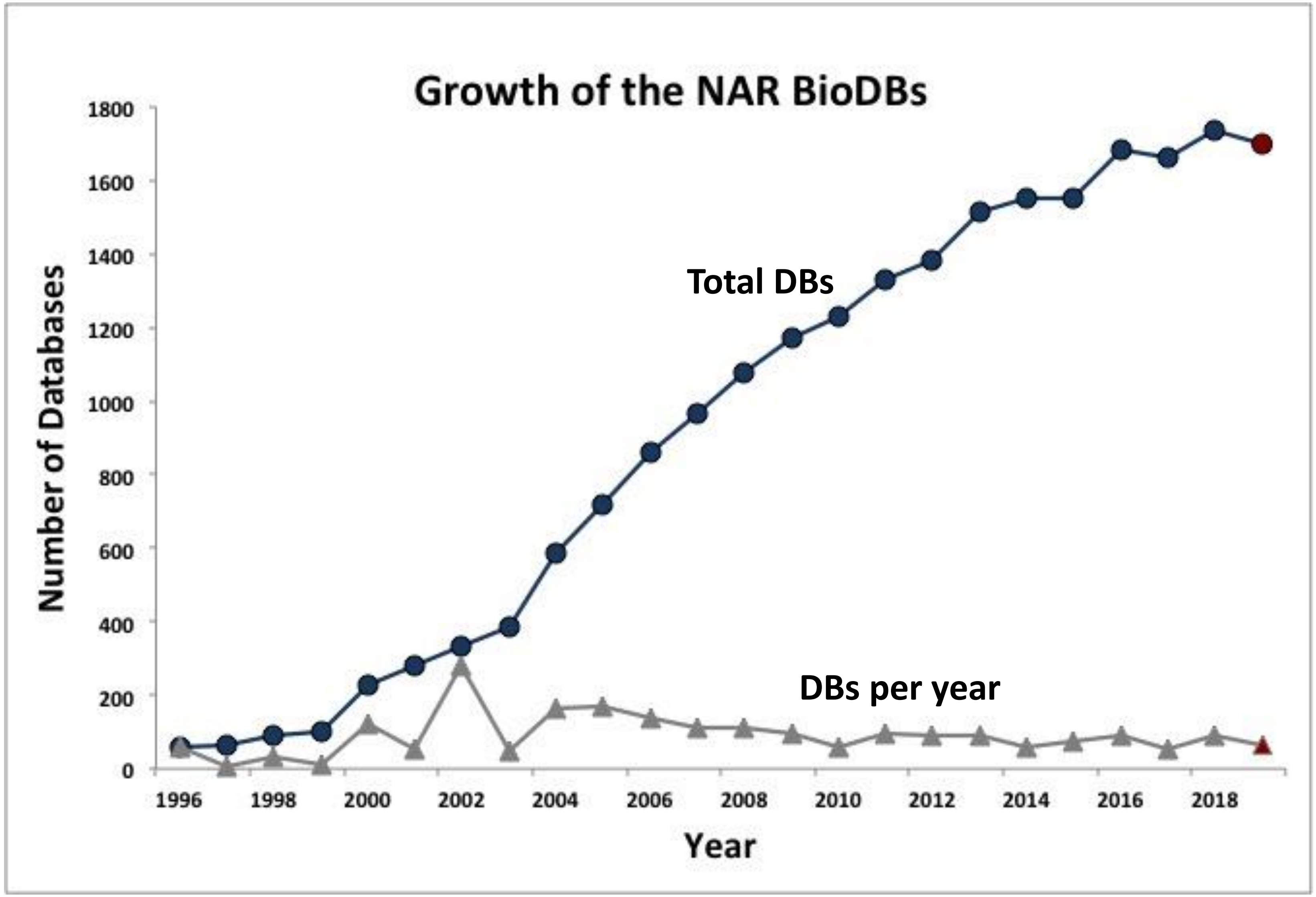

Relational databases first appear.
World Wide Web
1960s
1970s
1980s
1990s
2000s
The term "database" is coined.
Object-Oriented Database
Non-relational databases reemerge.

Healthcare and life sciences data sources

Drug Research
Social Media
Patient Records
Gene Sequencing
Test Results
Claims
Home Monitoring
Mobile Apps

4Vs:

- **Volume – high-throughput technologies**
- **Variety – diverse data types, different formats, structured vs. unstructured data**
- **Velocity – data streaming**
- **Veracity – trust worthiness of data**


Growth of the NAR BioDBs
Number of Databases
0
200
400
600
800
1000
1200
1400
1600
1800
Total DBs
DBs per year
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Year

What is (not) a database?

- **It’s not just a file**
- **It’s not just an Excel spreadsheet**
- **It’s an organized collection of related information that can easily be accessed, managed, and updated**

Key database concepts

- **Data integrity** is the assurance that data are correct, complete and consistent (data correctly reflects the real world)
- **Data redundancy** occurs if data are duplicated between files
- **Data dependency** defines linkage between data files and their order of entry
- **Data security** refers to data being protected so that only authorized personnel can access them
  - **Data ethics:** fairness, privacy, transparency, and accountability

Relational database (SQL database)

- **The relational model was introduced by E.F. Codd in 1970, which is based on the mathematical set theory**
- **A relational database management system (RDBMS) is a computer application (software) of the relational data model (e.g., MS SQLServer, MySQL, Oracle, …)**
- **It has become an industry standard with a standard query language (SQL)**
- **Relational databases have widely been used to manage data in different domains**

Components of Relational Database

- **A table (relation) represents some class of objects (e.g., patients, doctors, drugs, hospitals)**
- **Each table consists of columns (attributes) and rows (tuples).**
  - **Each column represents some attribute of the object represented by the table (e.g., patient id, patient name)**
  - **Each row corresponds to an instance of the object represented by the table (e.g., each row in the Patient table represents a patient who has a specific patient id and name.)**

Formal definition of relations

- A relation is a collection of tuples
- Given a collection of types Ti (i=1,2, …n)
  - Each tuple t is a set of ordered triples of the form <Ai, Ti, vi>, where Ai is an attribute name, Ti is a type name, and vi is a value of type Ti
  - The value n is the degree or arity of t
  - Each ordered triple <Ai, Ti, vi> is a component of t
  - Each ordered pair <Ai, Ti> is an attribute of t
  - The complete set of attributes is the heading of t
- Properties of tuples
  - Every tuple contains exactly one value for each attribute
  - There is no left-to-right ordering to the components of a tuple
  - Every subset of a tuple is a tuple (and every subset of a heading is a heading)

How to organize data into tables

Keys

- Primary key: Every table should have a primary key comprising a single or multiple columns that contain unique values. A primary key is the unique identifier of a table row (e.g., “sample id” is the primary key for the Sample table)
- Foreign key: it is a key taken from a different table. For example, in the Experiment table, the “sample id” is the foreign key to the Sample table.

Data redundancy

- **Data redundancy occurs (accidentally or intentionally) when the same piece of data is stored in two or more separate places**
- **It can increase database size and cause such anomalies as data inconsistency**

Patient ID	Name	Address City	DOB
401	Adam	New Haven	1/1/1970
402	Alex	Bridgeport	3/16/1964
403	Stuart	Fairfield	8/6/2000
401	Adam	Norwalk	2/1/1970

Normalization

- **Normalization is a *process* in which we systematically organize columns and tables to eliminate anomalies due to data redundancy**
- **It involves decomposing a (de-normalized) table into less redundant (smaller) tables without losing information**
- **The objective is to isolate data so that additions, deletions, modifications of data can be made in just one table and then propagated to other tables using foreign keys.**
- **Normalization is a trade-off between data redundancy and performance.**
  - **Normalizing a table reduces data redundancy but introduces the need for joins when all of the data is required for a report query.**
- **Normal Form: A set of tables free from a certain set of addition, deletion and modification anomalies.**

Different Normal Forms

- **First normal form (1NF)**
- **Second normal form (2NF)**
- **Third normal form (3NF)**
- **Boyce-Codd normal form (BCNF)**
- **Fourth normal form (4NF)**
- **Fifth normal form (5NF)**
- **Domain-Key normal form (DK/NF)**
- …

First Normal Form

- **Each column value must be a single value only.**
- **All values for a given column must be of the same data type.**
- **Each column name must be unique.**
- **The order of columns is insignificant**
- **The order of the rows is insignificant**
- **No two rows in a table can be identical.**

First Normal Form Example

Patient ID	Name	Age	ICD10code	Diagnosis
401	Adam Smith	45	311	Covid
402	Jane Doe	54	N18.9	CKD
403	Tom Steward	67	C18.2	Colon cancer

Second Normal Form

- **A table is in second normal form (2NF) if it is in 1NF and if all of its non-key columns are dependent on all of the *key*.**
  - **A table is in second normal form if it is free from partial-key dependencies**
- **Tables that have a single column for a key are automatically in 2NF.**
  - **This is one reason why we often use artificial identifiers (non-composite keys) as keys.**
- **To achieve second normal form, we may need to split a table into multiple tables and match rows between tables using primary and foreign keys**

Second Normal Form Example

Patient ID	Name	Age	ICD10code	Diagnosis
401	Adam Smith	45	311	Covid
402	Jane Doe	54	N18.9	CKD
403	Tom Steward	67	C18.2	Colon cancer

Patient ID	Name	Age	ICD10code
401	Adam Smith	45	311
402	Jane Doe	54	N18.9
403	Tom Steward	67	C18.2

ICD10code	Diagnosis
311	Covid
N18.9	CKD
C18.2	Colon cancer

Third Normal Form

- **Every non-primary key column must be dependent on primary key**
- **There should not be the case that a non-primary key column is determined by another non-primary key (*transitive dependency)***
  - **Patient (ID, Name, DOB, Zipcode, Country)**
- ***A table is in 3NF if the following are true:***
  - ***it is in 2NF***
  - ***All transitive dependencies* are removed**

Patient (ID, Name, DOB, Zip)

Address (Zipcode, Country)

Entity Relationship Diagram (ERD)

What is ERD

- **It is a data model associated with a diagrammatic method (P. Chen 1976) used to conduct/view data modeling**
- **It describes the attributes of and the relationship between entities (data objects)**
- **DBA uses ERD to perform data modeling and explain the diagram to stakeholders**

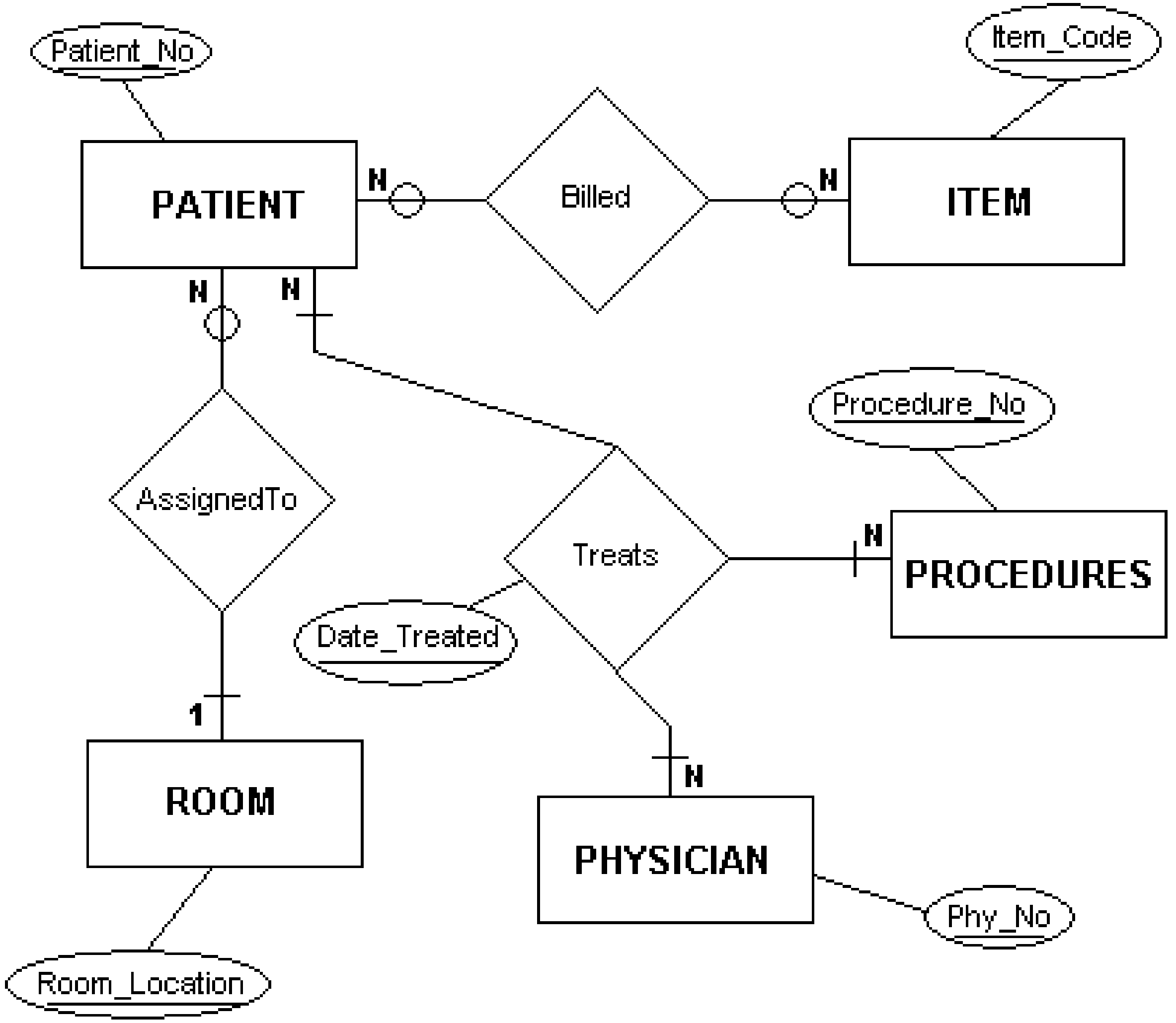
Primary Components of ERD

- **Entity represents a collection of objects in the real world (e.g., person, place, event)**
- **Attribute is a named property or characteristic of an entity**
- **Relationship is an association between the instances of one or more entities**

Relationship Cardinality

- **It expresses the minimum and maximum number of occurrences of one entity for a single occurrence of the other**
  - **One-to-One (1:1)**
  - **One-to-Many (1:N)**
  - **Many-to-Many (M:N)**

Example ERD (Hospital Database)



What is UML?

- **Unified Modeling Language**
- **It was developed by Grady Booch, Ivar Jacobson and James Rumbaugh in 1994–1996**
- **It is a general-purpose modeling language in software engineering**
- **It is intended to provide a standard way to visualize the design of a system**
- **UML was adopted as a standard by the Object Management Group (OMG) in 1997**
- **UML was published by the International Organization for Standardization (ISO) as an approved ISO standard in 2005**

UML as a visual diagram

- **Diagrams in UML can be broadly classified as:**
  - **Structural Diagrams – Capture static aspects or structure of a system including Component Diagrams, Object Diagrams, Class Diagrams and Deployment Diagrams.**
  - **Behavior Diagrams – Capture dynamic aspects or behavior of the system including: Use Case Diagrams, State Diagrams, Activity Diagrams and Interaction Diagrams.**

UML Diagram

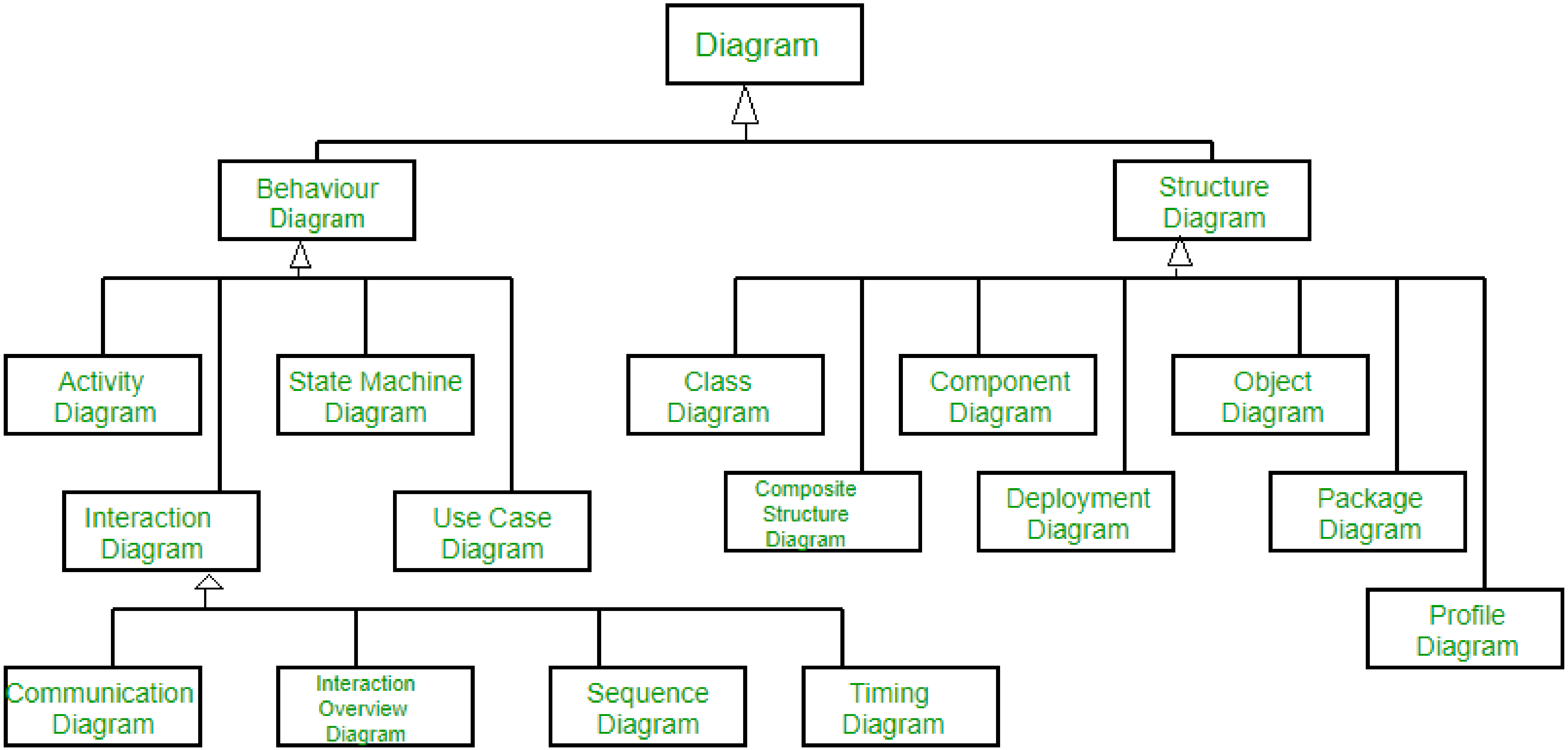
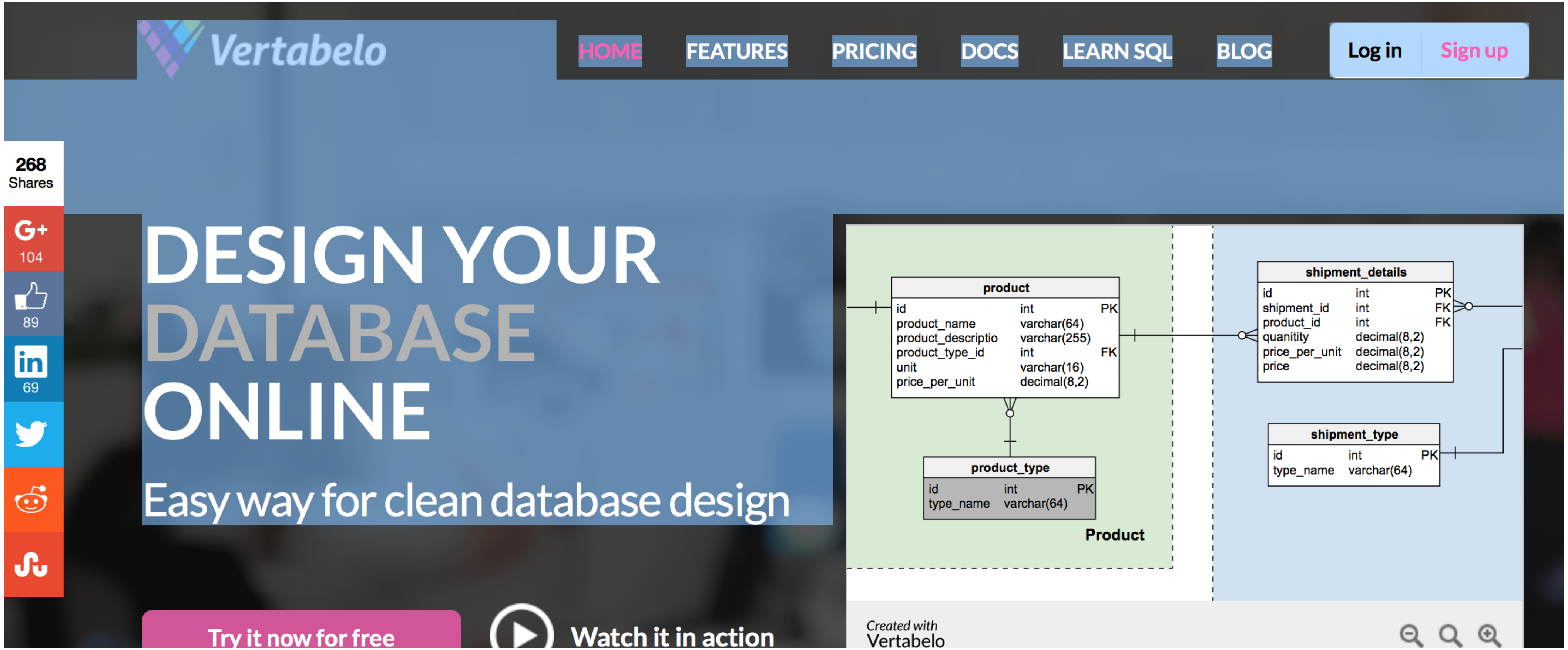


Diagram
Behaviour Diagram
Structure Diagram
Activity Diagram
State Machine Diagram
Interaction Diagram
Use Case Diagram
Communication Diagram
Interaction Overview Diagram
Sequence Diagram
Timing Diagram
Class Diagram
Component Diagram
Object Diagram
Composite Structure Diagram
Deployment Diagram
Package Diagram
Profile Diagram

Vertabelo (https://www.vertabelo.com/)



DESIGN YOUR DATABASE ONLINE

Easy way for clean database design

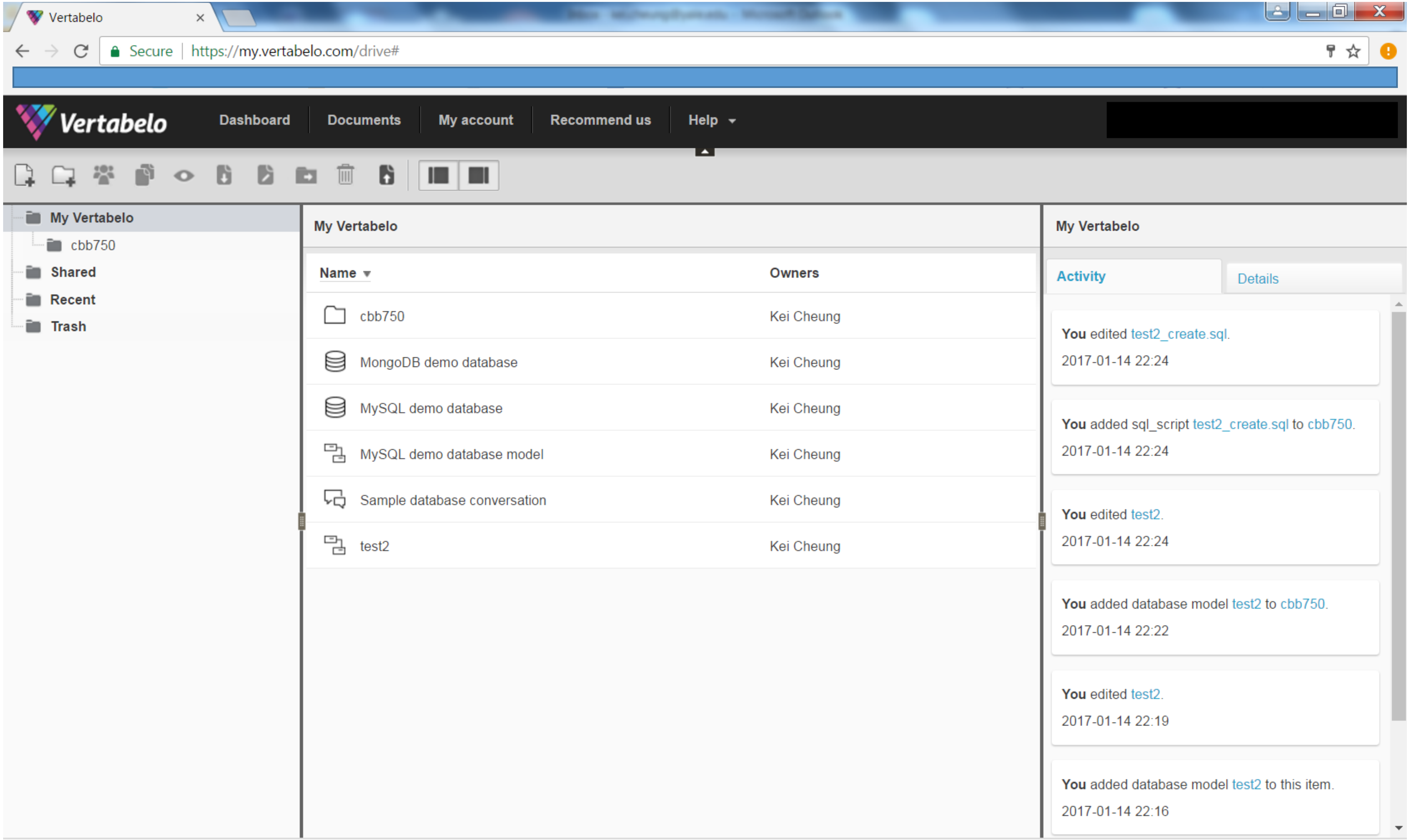
product		
id	int	PK
product_name	varchar(64)	
product_descriptio	varchar(255)	
product_type_id	int	FK
unit	varchar(16)	
price_per_unit	decimal(8,2)	

product_type		
id	int	PK
type_name	varchar(64)	

Product

shipment_details		
id	int	PK
shipment_id	int	FK
product_id	int	FK
quanitity	decimal(8,2)	
price_per_unit	decimal(8,2)	
price	decimal(8,2)	

shipment_type		
id	int	PK
type_name	varchar(64)	



[redacted]

My Vertabelo

Name ▾	Owners
cbb750	Kei Cheung
MongoDB demo database	Kei Cheung
MySQL demo database	Kei Cheung
MySQL demo database model	Kei Cheung
Sample database conversation	Kei Cheung
test2	Kei Cheung

My Vertabelo

Activity | Details

You edited test2_create.sql.
2017-01-14 22:24

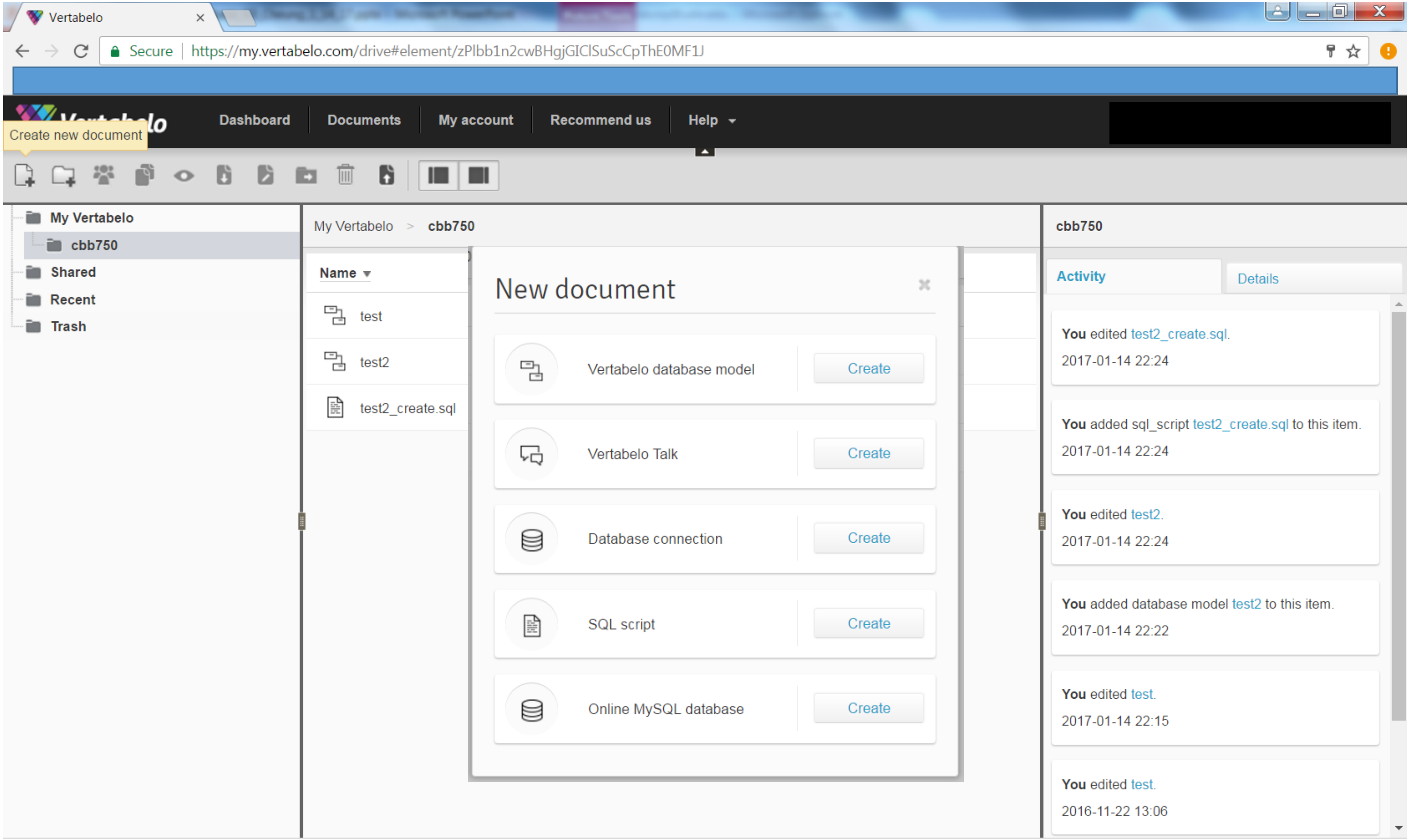
You added sql_script test2_create.sql to cbb750.
2017-01-14 22:24

You edited test2.
2017-01-14 22:24

You added database model test2 to cbb750.
2017-01-14 22:22

You edited test2.
2017-01-14 22:19

You added database model test2 to this item.
2017-01-14 22:16



[redacted]

New document

Vertabelo database model	Create
Vertabelo Talk	Create
Database connection	Create
SQL script	Create
Online MySQL database	Create

You edited test2_create.sql.
2017-01-14 22:24

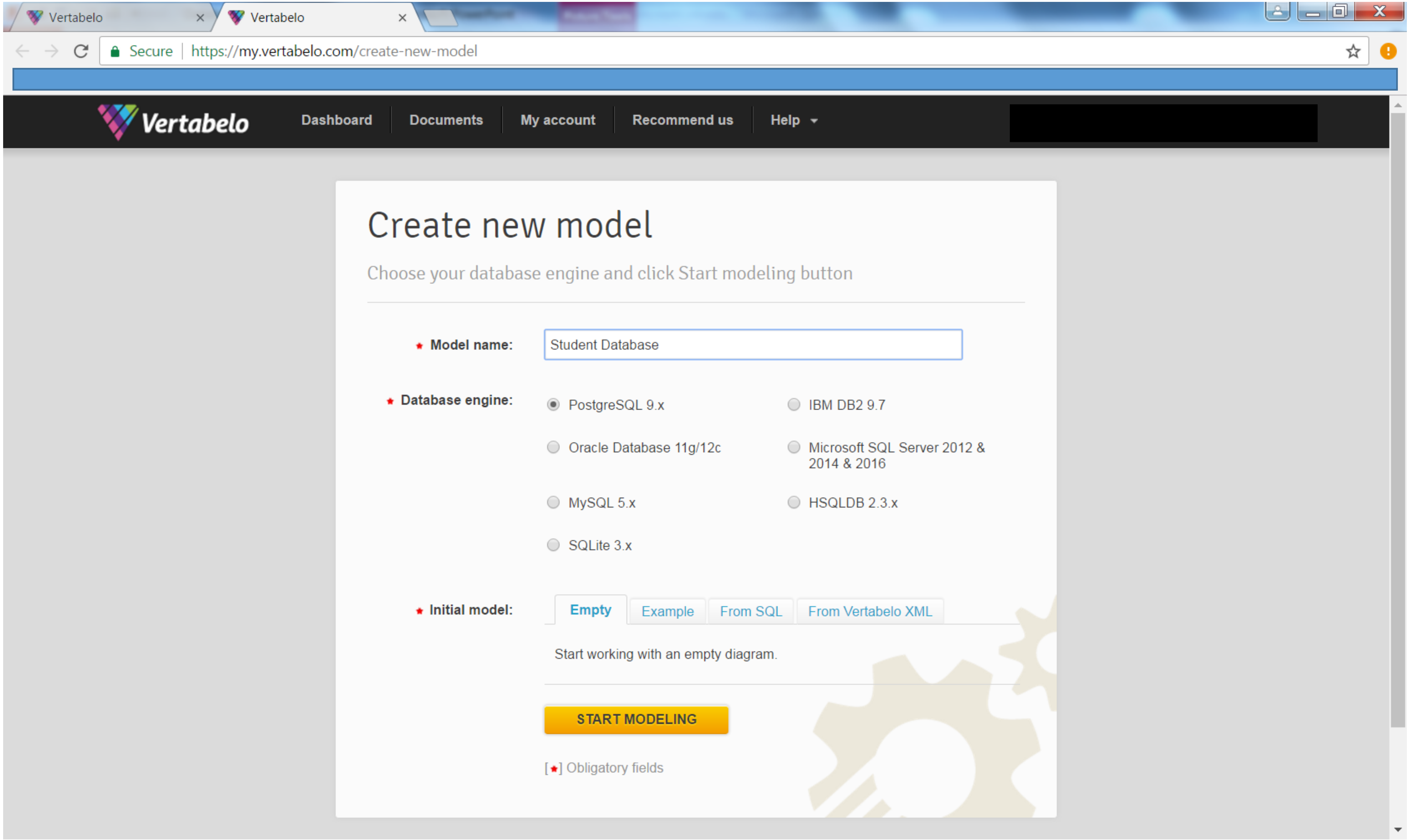
You added sql_script test2_create.sql to this item.
2017-01-14 22:24

You edited test2.
2017-01-14 22:24

You added database model test2 to this item.
2017-01-14 22:22

You edited test.
2017-01-14 22:15

You edited test.
2016-11-22 13:06



[redacted]

Create new model

Choose your database engine and click Start modeling button

* Model name: Student Database

* Database engine:

● PostgreSQL 9.x ○ IBM DB2 9.7

○ Oracle Database 11g/12c ○ Microsoft SQL Server 2012 & 2014 & 2016

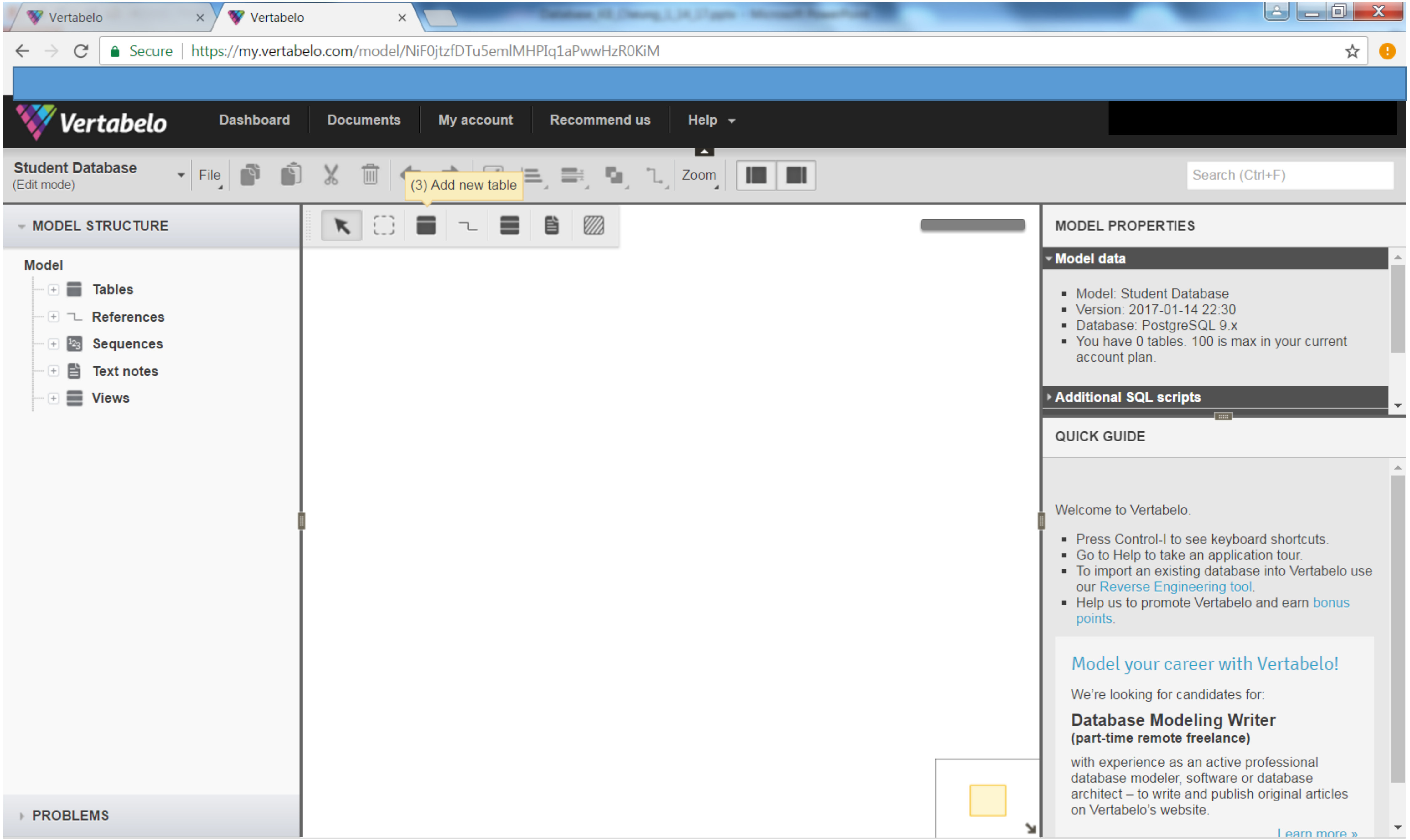
○ MySQL 5.x ○ HSQLDB 2.3.x

○ SQLite 3.x

* Initial model: [✓ Empty] Example From SQL From Vertabelo XML

Start working with an empty diagram.

[*] Obligatory fields



(3) Add new table

- Model: Student Database
- Version: 2017-01-14 22:30
- Database: PostgreSQL 9.x
- You have 0 tables. 100 is max in your current account plan.

Welcome to Vertabelo.

- Press Control-I to see keyboard shortcuts.
- Go to Help to take an application tour.
- To import an existing database into Vertabelo use our Reverse Engineering tool.
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with experience as an active professional database modeler, software or database architect – to write and publish original articles on Vertabelo's website.

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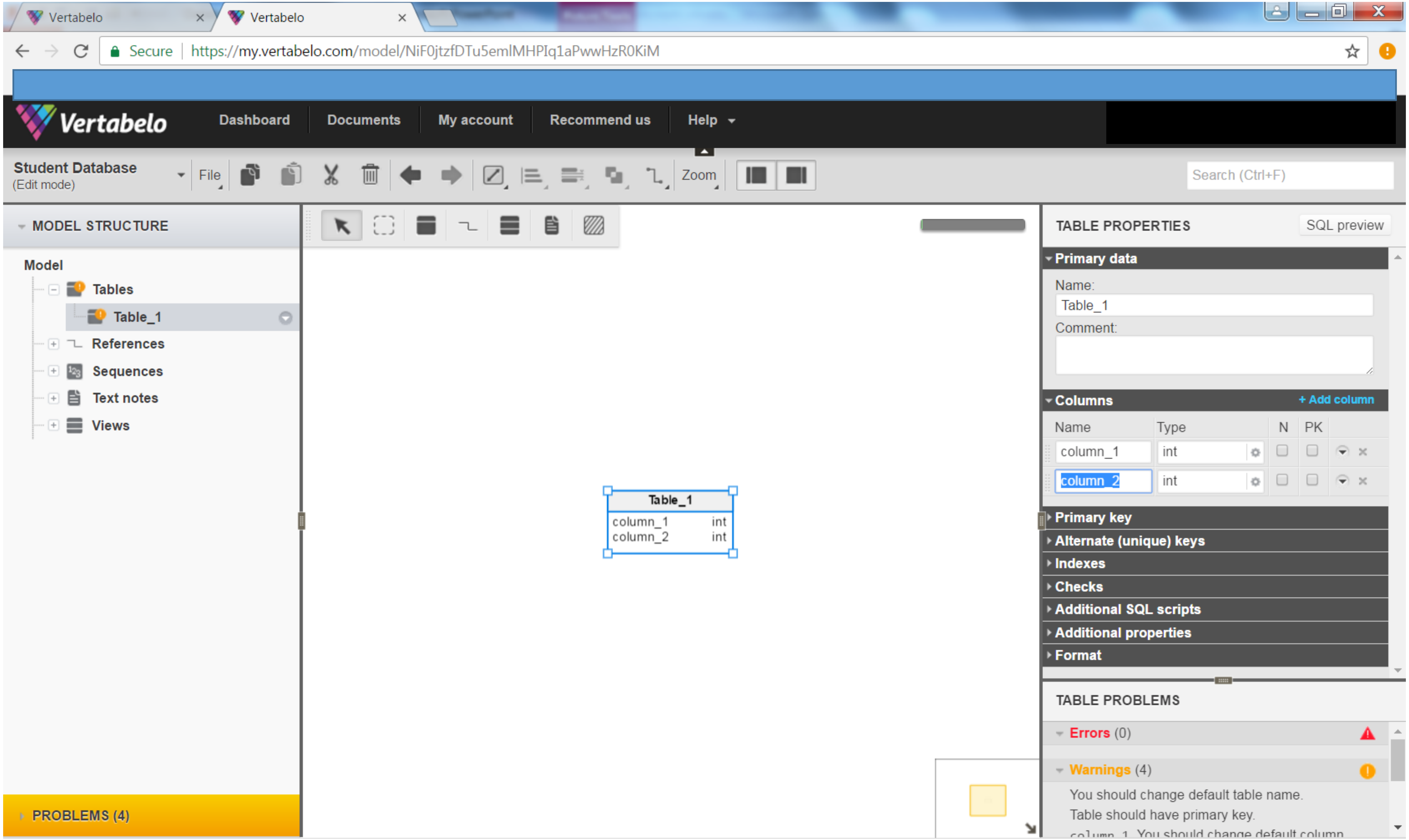


Name: Table_1

Comment:

Name	Type	N	PK
column_1	int	□	□
column_2	int	□	□

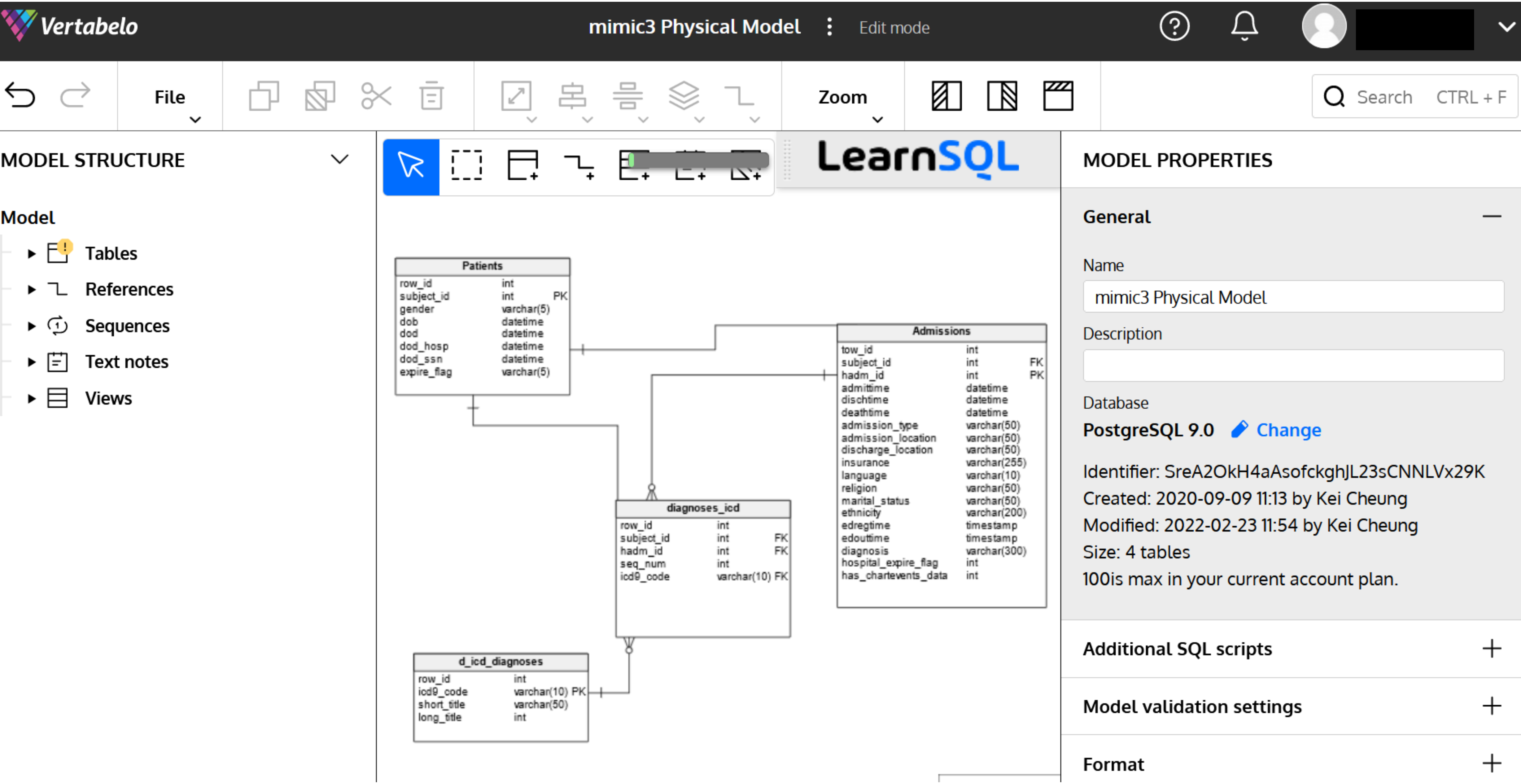
Errors (0)

Warnings (4)

You should change default table name.

Table should have primary key.

column_1 You should change default column



mimic3 Physical Model

[redacted]

Patients

row_id	int	
subject_id	int	PK
gender	varchar(5)	
dob	datetime	
dod	datetime	
dod_hosp	datetime	
dod_ssn	datetime	
expire_flag	varchar(5)	

Admissions

tow_id	int	
subject_id	int	FK
hadm_id	int	PK
admittime	datetime	
dischtime	datetime	
deathtime	datetime	
admission_type	varchar(50)	
admission_location	varchar(50)	
discharge_location	varchar(50)	
insurance	varchar(255)	
language	varchar(10)	
religion	varchar(50)	
marital_status	varchar(50)	
ethnicity	varchar(200)	
edregtime	timestamp	
edouttime	timestamp	
diagnosis	varchar(300)	
hospital_expire_flag	int	
has_chartevents_data	int	

diagnoses_icd

row_id	int	
subject_id	int	FK
hadm_id	int	FK
seq_num	int	
icd9_code	varchar(10)	FK

d_icd_diagnoses

row_id	int	
icd9_code	varchar(10)	PK
short_title	varchar(50)	
long_title	int	

General

Name: mimic3 Physical Model

Description:

Database: PostgreSQL 9.0 Change

Identifier: SreA2OkH4aAsofckghJL23sCNNLVx29K
Created: 2020-09-09 11:13 by Kei Cheung
Modified: 2022-02-23 11:54 by Kei Cheung
Size: 4 tables
100is max in your current account plan.

On-Line Transaction Processing (OLTP)

What is OLTP?

- **It is a class of information systems (e.g., databases) that facilitate and manage transaction-oriented applications, typically for data entry and retrieval transactions**
- **A database that is based on a normalized relational model is considered an OLTP application. It supports the following transactions:**
  - **Insert new rows**
  - **Update existing rows**
  - **Delete rows**
  - **Select rows**
- **A database transaction must be atomic, consistent, isolated and durable (ACID)**

Structured Query Language (SQL)

- **It is a standard programming language for creating (CREATE) relational databases and tables as well as retrieving (SELECT), adding (INSERT), deleting (DELETE) and updating (UPDATE) data in a relational database**
- **It is compliant with ANSI and ISO standards**

SQL Statement (CREATE DATABASE/TABLE)

```
CREATE DATABASE Patient_DB;

CREATE TABLE Patient_DB.Patient
(
        ID int,
        Name varchar (50),
        Address varchar (250),
        Age smallint
        Sex varchar (2)
);
```

INSERT Statement

```
INSERT INTO Patient_DB.Patient
(ID, Name, Address, Age, Sex)
VALUES (1, ‘John Doe’, ‘XYZ’, 40, ‘M’)
…
```

ID	Name	Address	Age	Sex
1	John Doe	XYZ	40	M
2	Jane Smith	ABC	34	F
3	Mary Queen	PQSRT	46	F
4	Mike Lee	DWQER	60	M

UPDATE Statement

```
UPDATE Patient_DB.Patient
SET AGE=41
WHERE ID=1
```

ID	Name	Address	Age	Sex
1	John Doe	XYZ	41	M
2	Jane Smith	ABC	34	F
3	Mary Queen	PQSRT	46	F
4	Mike Lee	DWQER	60	M

DELETE Statement

```
DELETE Patient_DB.Patient
WHERE Name=‘Mike Lee’
```

ID	Name	Address	Age	Sex
1	John Doe	XYZ	41	M
2	Jane Smith	ABC	34	F
3	Mary Queen	PQSRT	46	F

SELECT Statement

```
SELECT ID, Name, Age, Sex
FROM Patient_DB.Patient
WHERE Age>=40
ORDER BY Age
```

ID	Name	Address	Age	Sex
1	John Doe	XYZ	40	M
2	Jane Smith	ABC	34	F
3	Mary Queen	PQSRT	46	F
4	Mike Lee	DWQER	60	M

SELECT Statement (Aggregation)

```
SELECT Sex, avg(Age)
FROM Patient_DB.Patient
GROUP BY SEX
```

```
Results: M 50
         F   40
```

ID	Name	Address	Age	Sex
1	John Doe	XYZ	40	M
2	Jane Smith	ABC	34	F
3	Mary Queen	PQSRT	46	F
4	Mike Lee	DWQER	60	M

SELECT Statement (JOIN)

SELECT A.*, B.Report_Text

FROM Patient_DB.Patient AS A

INNER JOIN Patient_DB.LabTest. AS B

ON A.ID = B.Patient_ID

ID	Name	Address	Age	Sex
1	John Doe	XYZ	40	M
2	Jane Smith	ABC	34	F
3	Mary Queen	PQSRT	46	F
4	Mike Lee	DWQER	60	M

Patient_ID	ID	Report_Text
1	1	……
2	2	…….

ID	Name	Address	Age	Sex	Report_Text
1	John Doe	XYZ	40	M	**.....**
2	Jane Smith	ABC	34	F	**.....**

CREATE VIEW

```
CREATE VIEW Patient_Doc AS
SELECT A.*, B.Report_Text
FROM Patient_DB.Patient AS A
INNER JOIN Patient_DB.LabTest. AS B
ON A.ID = B.Patient_ID
```

```
SELECT * FROM Patient_Doc
WHERE Age>45
```

ID	Name	Address	Age	Sex	Report_Text
3	Mary Queen	PQSRT	46	F	…..
4	Mike Lee	DWQER	60	M	…..

Other Types of SQL Statements

- **TRUNCATE TABLE**
- **DROP TABLE**
- **CREATE INDEX (boost query performace)**
  - **Full-Text index (e.g., part of MS SQLServer)**

From OLTP to OLAP (On-Line Analytical Processing)

OLAP Overview

- **OLTP databases are tuned to small/medium size of data with relatively simple queries**
- **Some applications use fewer but more time-consuming analytic queries**
- **New architectures (data warehouses) have been developed to handle such analytic queries efficiently (De-normalization)**

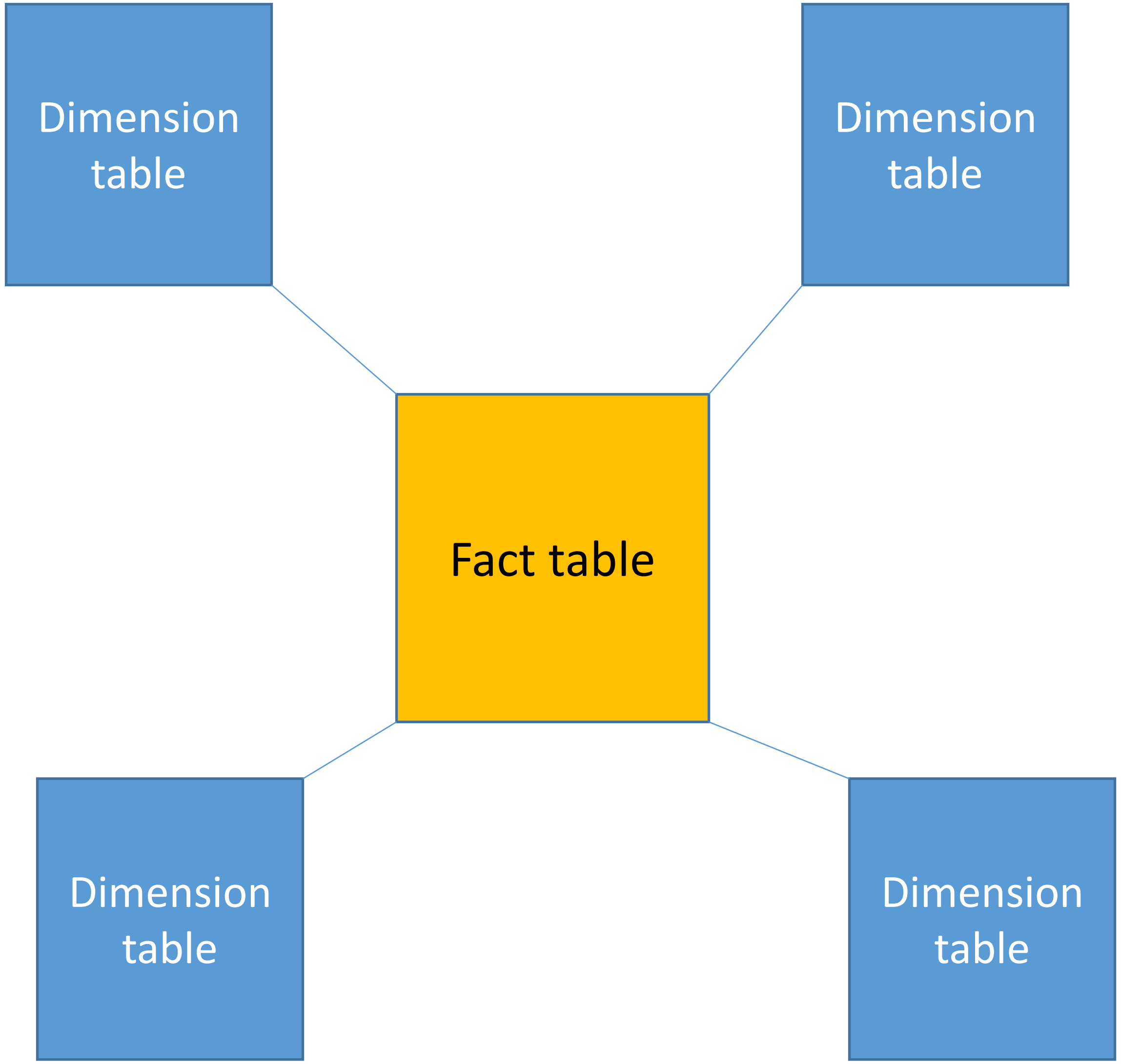
OLAP Example Queries

- **Amazon analyzes purchases by its customers to identify products of likely interest to customers**
- **Analysts at Wal-Mart look for merchandise items with increasing sales in some region**

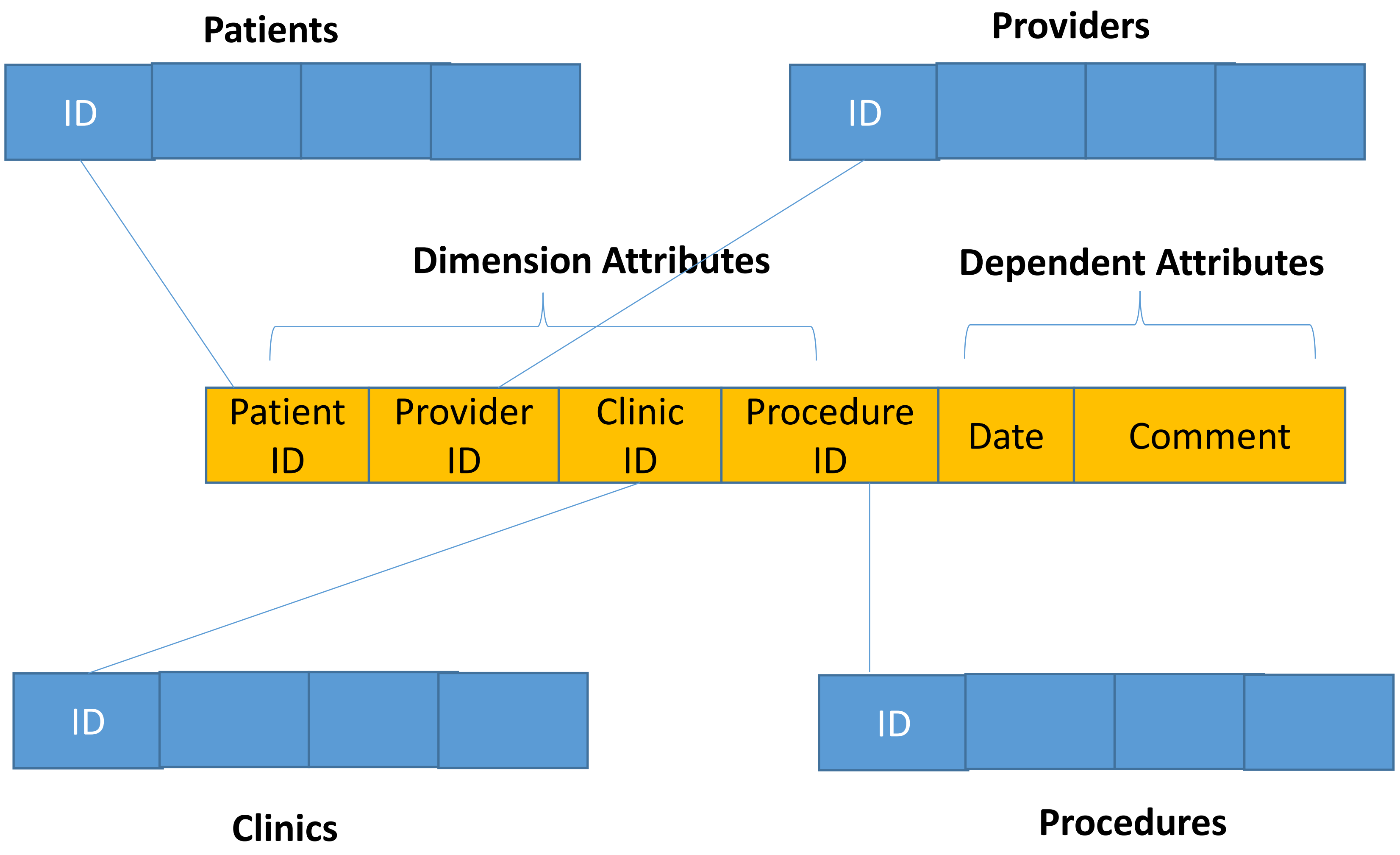
Data Warehouse

- **The most common form of database integration**
  - **Copy source databases into a single database (data warehouse)**
  - **Update the data warehouse periodically (in batch mode)**
  - **Support analytic queries using a dimensional data model (vs. a normalized entity-relationship model)**
- **Example: VA CDW**

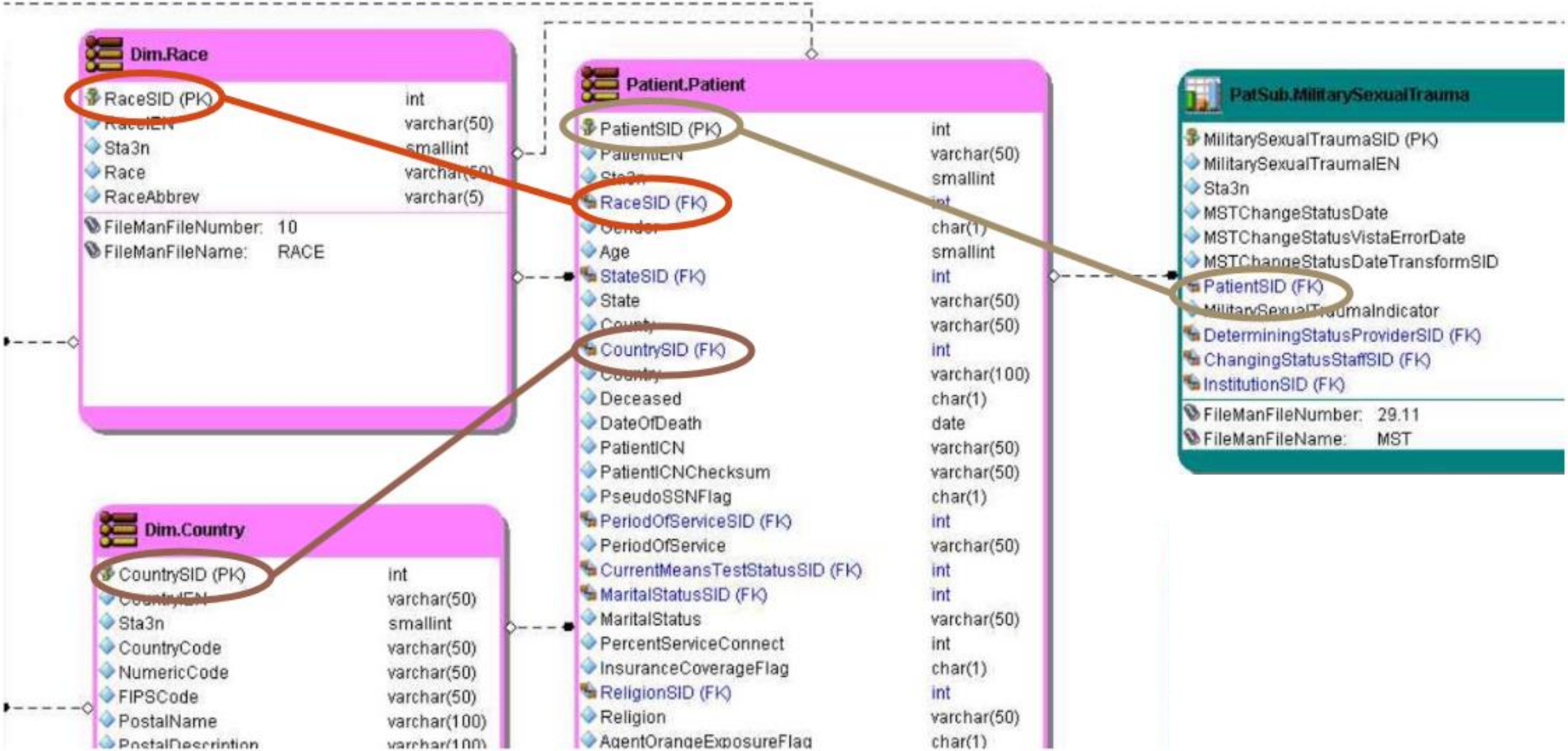
Star Schema


Dimension table
Dimension table
Fact table
Dimension table
Dimension table

Star Schema Example



Corporate Data Warehouse



Dim.Race

RaceSID (PK)	int
RaceIEN	varchar(50)
Sta3n	smallint
Race	varchar(50)
RaceAbbrev	varchar(5)

FileManFileNumber: 10
FileManFileName: RACE

Patient.Patient

PatientSID (PK)	int
PatientIEN	varchar(50)
Sta3n	smallint
RaceSID (FK)	int
Gender	char(1)
Age	smallint
StateSID (FK)	int
State	varchar(50)
County	varchar(50)
CountrySID (FK)	int
Country	varchar(100)
Deceased	char(1)
DateOfDeath	date
PatientICN	varchar(50)
PatientICNChecksum	varchar(50)
PseudoSSNFlag	char(1)
PeriodOfServiceSID (FK)	int
PeriodOfService	varchar(50)
CurrentMeansTestStatusSID (FK)	int
MaritalStatusSID (FK)	int
MaritalStatus	varchar(50)
PercentServiceConnect	int
InsuranceCoverageFlag	char(1)
ReligionSID (FK)	int
Religion	varchar(50)
AgentOrangeExposureFlag	char(1)

PatSub.MilitarySexualTrauma

MilitarySexualTraumaSID (PK)
MilitarySexualTraumaIEN
Sta3n
MSTChangeStatusDate
MSTChangeStatusVistaErrorDate
MSTChangeStatusDateTransformSID
PatientSID (FK)
MilitarySexualTraumaIndicator
DeterminingStatusProviderSID (FK)
ChangingStatusStaffSID (FK)
InstitutionSID (FK)

FileManFileNumber: 29.11
FileManFileName: MST

Dim.Country

CountrySID (PK)	int
CountryIEN	varchar(50)
Sta3n	smallint
CountryCode	varchar(50)
NumericCode	varchar(50)
FIPSCode	varchar(50)
PostalName	varchar(100)
PostalDescription	varchar(100)

Example Queries

- **Compare numbers of patient visits across different clinics for a given year**
- **Which are the top 10 most performed procedures among all clinics from 2010 to 2014**

The End

Thanks!