How to design a database?

Heli Helskyaho, Matias Helskyaho

KCDC 2024

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Introduction, Heli

- Graduated from University of Helsinki (Master of Science, computer science), currently a doctoral student, researcher and lecturer (databases, Multi-model/Converged Databases) at University of Helsinki
- Worked with Oracle products since 1993, worked for IT since 1990
- Data and Database!
- CEO for Miracle Finland Oy
- Oracle ACE Director
- Public speaker and an author
- Author of the book Oracle SQL Developer Data Modeler for Database Design Mastery (Oracle Press, 2015), co-author for Real World SQL and PL/SQL: Advice from the Experts (Oracle Press, 2016), Machine Learning for Oracle Database Professionals: Deploying Model-Driven Applications and Automation Pipelines (Apress, 2021), and Extending Oracle Application Express with Oracle Cloud Features: A Guide to Enhancing APEX Web Applications with Cloud-Native and Machine Learning Technologies (Apress, 2022)

A Oracle ACE Director

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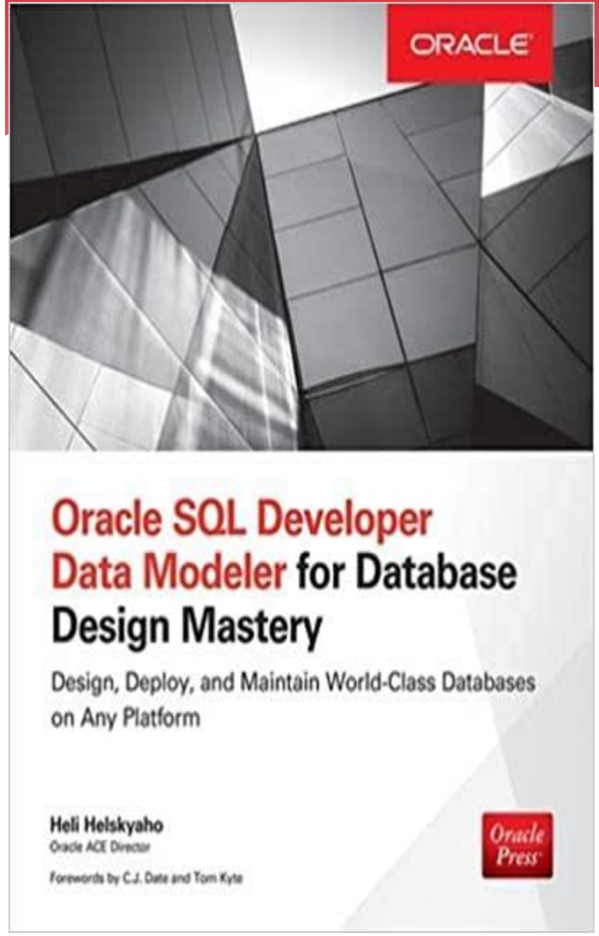
Books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Oracle SQL Developer Data Modeler for Database Design Mastery

Design, Deploy, and Maintain World-Class Databases on Any Platform

Heli Helskyaho
Oracle ACE Director

Forewords by C.J. Date and Tom Kyte

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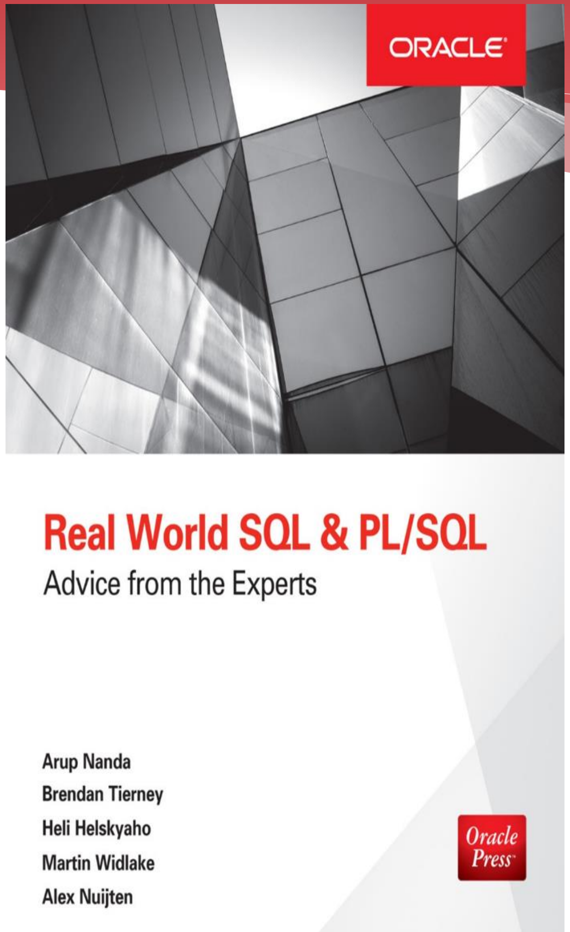
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Real World SQL & PL/SQL

Advice from the Experts

Arup Nanda
Brendan Tierney
Heli Helskyaho
Martin Widlake
Alex Nuijten

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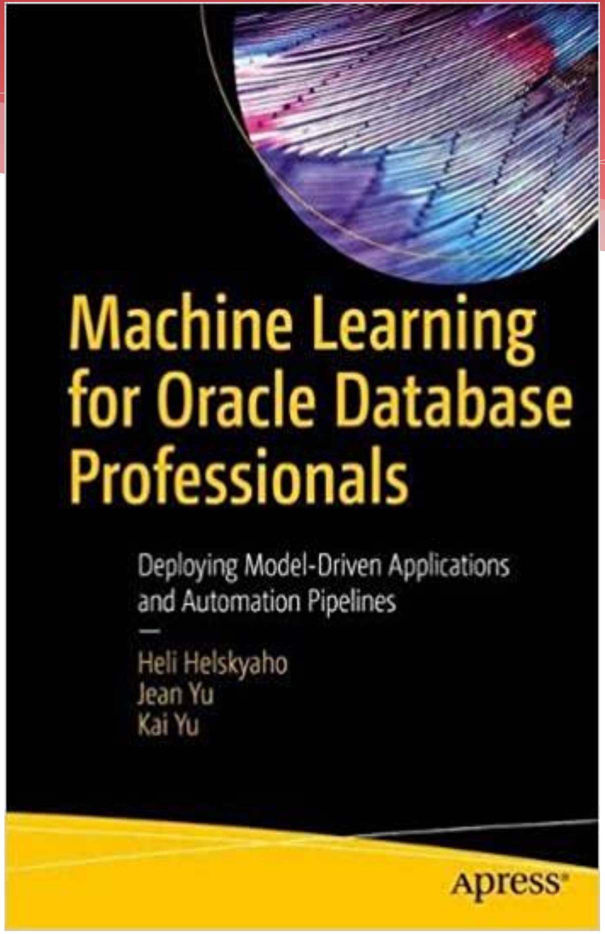
Machine Learning for Oracle Database Professionals

Deploying Model-Driven Applications and Automation Pipelines

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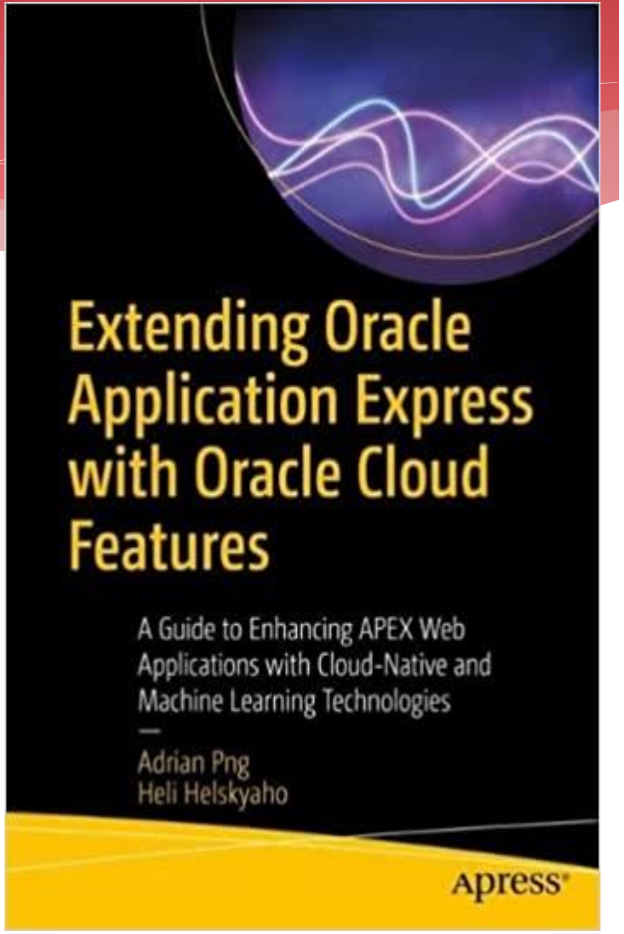
Extending Oracle Application Express with Oracle Cloud Features

A Guide to Enhancing APEX Web Applications with Cloud-Native and Machine Learning Technologies

Adrian Png
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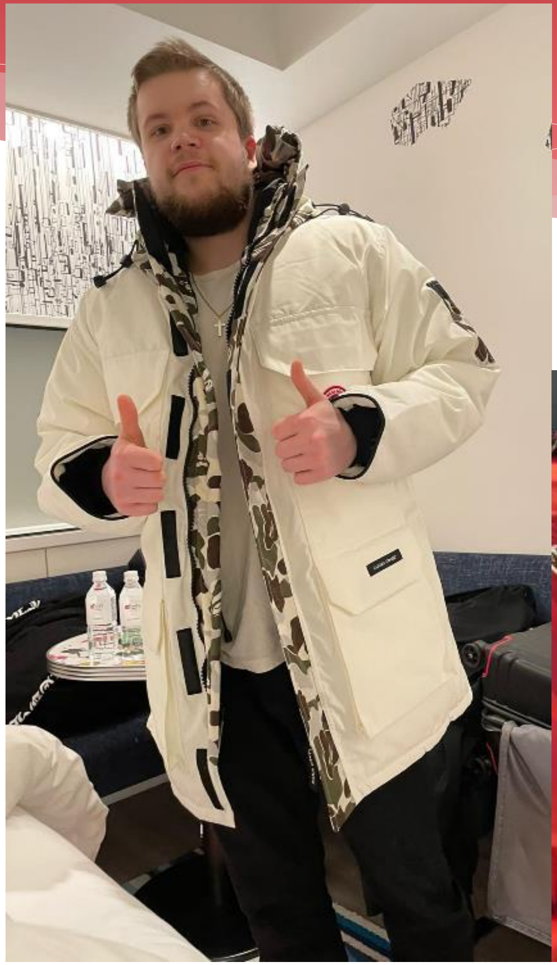
Matias

Oracle ACE Pro

- Consultant
  - Miracle Finland Oy
- Who am I?
  - On IT since birth
  - Professionally a couple of years
  - OCI, networks, IOT, ML, analytics,..
- Hobbies
  - Love learning cool stuff
  - Playing with tech devices



Why to design?

- ”Data is the most valuable property in our company”
- ”Why do we need to design the database? We already design the application!”

Why is designing the application not enough?

- Point of view (saving and retrieving data vs. UI)
- First increment vs. 20 years from now
- ”the whole picture” vs. increments
- Different goals/targets:
  - Code tables vs. Code files (how about the data integrity?)
  - How about analysis, reports, … everything else but the UI that the data is used for
- Same terminology, different meaning -> misunderstandings
- …

Why to model the data?

- To facilitate communication about the requirements
- To find the questions that should be asked
- To understand the requirements

What is database design?

- 4 (5) phases, over and over again
  - Requirement analysis (DM: logical)
  - Conceptual design (DM: logical)
  - Logical design (DM: relational)
  - Physical design (DM: physical)
  - (Transaction design) (DM: process)

Conceptual design

- Main idea: saving the data and retrieving it -> **DATA**
- Information needed: everything you can find
- Requirements and analysis usually half way -> need a lot of questions and answers
- Interview the end users! Officially, unofficially
- Model only the **target**, not the whole world

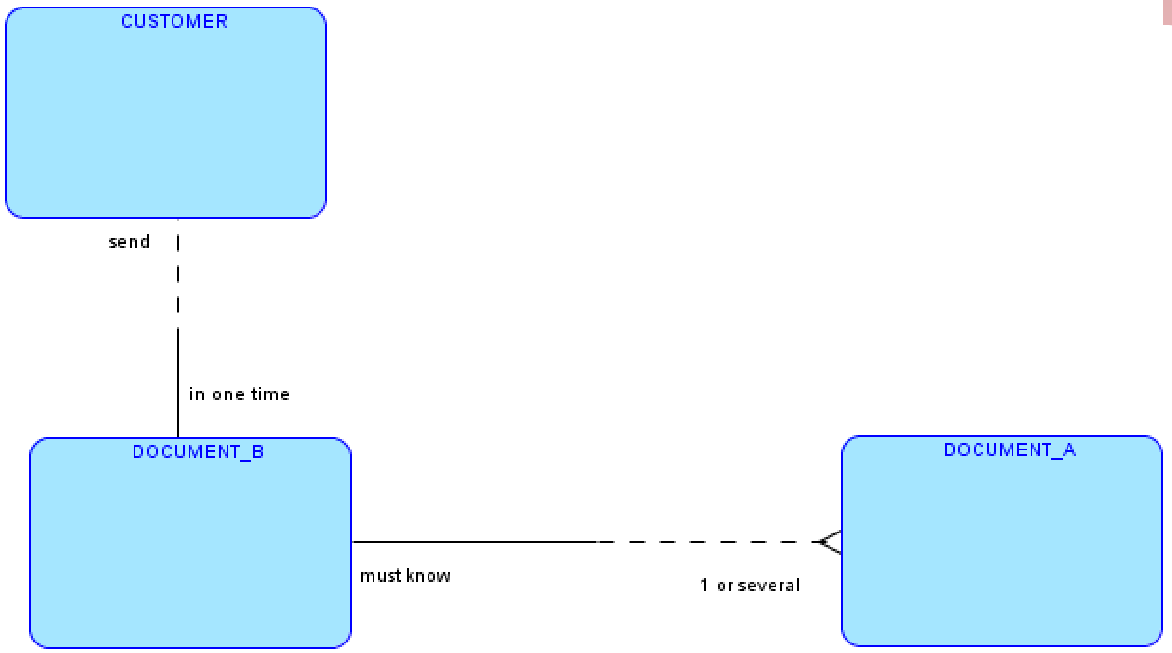
Conceptual design

- Use right **terminology** and clear names, much easier to communicate with the end users (one of the reasons to model!)
- Try to find and understand the **main** concepts and their relationships (these are the most difficult to change during the iterations)

Conceptual design, an example

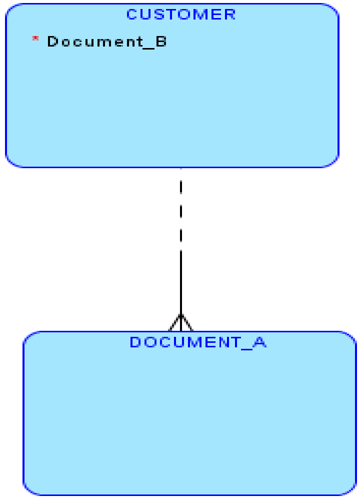
- ”At one time one will make 1 or more Document/-s A and exactly one Document B for a Customer. One must know exactly which Document B was with which Document/-s A.”
- EASY AND CLEAR!

Conceptual design, an example



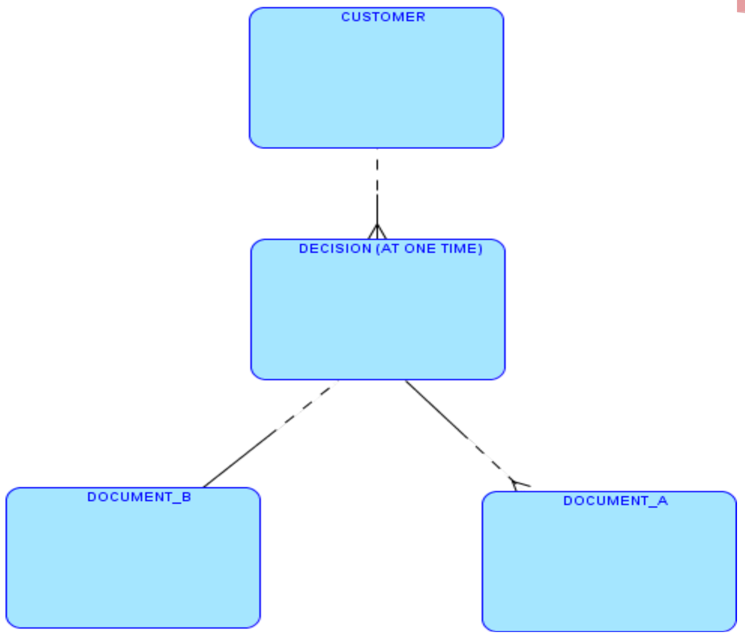
Conceptual design, an example

- OR?



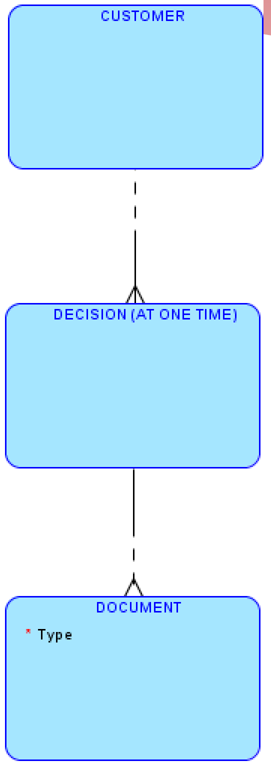
Conceptual design, an example

- OR?



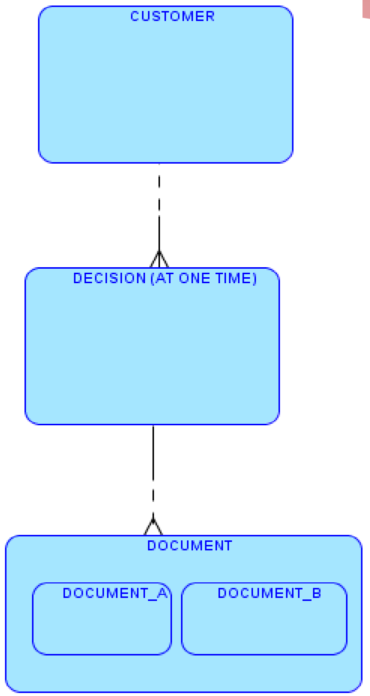
Conceptual design, an example

- OR?



Conceptual design, an example

- OR?



Conceptual design

- Or one of the other dozen different ways to model this requirement?

Conceptual design

- Modeling is **difficult** because
  - Spoken/written language is not exact
  - Usually all the ”important” things are those that ”everybody knows” so they are not told.
  - At this stage we do not know one important thing: how the data will be **retrieved**? That will be on iteration 9…
- Modeling is **mandatory** because when modeling the database designer realizes **what must be asked**!

Conceptual design, principles

- Everybody has their own and preferred ways of modeling (”handwriting”) and that is ok, but it is important to be **consistent** at least inside one model or system or application.
- Naming standards
- Documentation
- Comments from collegues
- Reviews, audits,…
- …

Design a Data Model for the Application

- Not the ”whole world”
- System definition: the scope and boundaries of the database application (helps to define entities, attributes and relationships, understanding how this system sits to the whole architecture and other IT systems)
- User views (helps to define roles and privileges, understanding how the system will be used)
- database and application design are parallel activities of the database system development lifecycle

Designing the database

1. **Requirement analysis:** finding and analysing the requirements the future end users have

Result: specification of user requirements

- **data** requirements
- **functional** requirements

Also requirements for security, performance, …

Designing the database

2. **Conceptual design.** ”Interpretation” of all the requirements to a formal presentation (conceptual model).

Result: conceptual schema, also textual documentation is possible/recommended (to make sure all the knowledge is documented)

This is a tool for communication with end users.

Requirement analysis and Conceptual design

- Collecting requirements and analyzing them
- Fact-finding: interviews, questionnaires, existing documentation,… (recordings)
- Requirements specifications
  - data requirements
  - functional requirements (performance, security, backup/recovery,..)
- Completely neutral to any technology

Requirement analysis and Conceptual design

- Why entity-relationship model (ER)
  - Defining the tables directly based on requirements can be too difficult and lead to a wrong db schema.
  - Based on a good ER it is easy to generate the relational model (which is at least on 3NF)
- Data Flow Diagrams (DFD)

Methods

- Collecting requirements
  - Centralized: all requirements merged into a single set of requirements
  - View: requirements for each user view as separate lists. Separate data models (local data model), that in later stage are merged as global data model.
  - A combination of these two
- Strategy
  - bottom-up
  - top-down
  - Inside-out
  - mixed

ER model, An Entity Type

- A group of objects with the same properties
- In spoken language: an Entity, a real life object (”A Customer”, ”An Invoice”)
- ”A noun”

Strong and weak entity

- strong entity: is not existence-dependent on some other entity (“Customer”, “Invoice”)
- weak entity: is existence-dependent on another entity (“Invoiceline”)
  - owner entity is identifying
  - identifying relationship

ER model, An Attibute

- Attribute is a property of an entity or a relationship (”The Firstname”, ”The OrderDate”)

ER model, An Attibute

- Atomic (”Firstname”)
- Composite attribute (”Name” = ”Firstname”+”Lastname”)
- Multivalued/set-valued (”Phonenumber”)
- Derived attribute (”Age”, ”Duration”)
- A Key (”StudentID”)
- Mandatory/non-mandatory (NULLs)

ER model, A Relationship Type

- In spoken language: a relationship
- A Relationship between 2 or more entities
- Entities *participate* the relationship
- An Entity can participate a relationship in different Roles (Recursive Relationship)
- *Degree* of a relationship is the number of participating entities in a relationship.
- A relationship can have its own Attributes
- ”A verb”

ER model, A Relationship

- Constraints
  - **Cardinality** constraint
    - 1:1
    - 1:m
    - m:1
    - m:n
  - **Participation** constraint
    - Total/partial (mandatory/optional)

ER model, A Key

- A **Candidate Key:** The minimal set of attributes that uniquely identifies each occurrence of an entity.
- Composite key is a candidate key that consists of two or more attributes.
- The **Primary Key:** one selected Candidate Key to identify each occurrence of an entity. Other possible candidate keys are called **alternate keys.**
- Which one to choose? (will it stay unique, not changing, data type, lenght,...)

ER model, A Key

- The Primary Key
  - Natural Key
  - Surrogate Key
  - A combination of these two…
- Not a required feature for an ER model, but relational model needs a Primary Key.

ER model, A Key

- Natural Key usually more efficient because joins are sometimes not needed at all
- A surrogate key is not often used in retrieving data (because it has no meaning to the business), but PK always has an index -> wasted space
- Surrogate does not stop inserting logical duplicates (UK needed)

Designing

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Avoid Redundance

- A wrong place for an attribute will cause redundancy
  - For example Country in the address entity
- Too many relationships may cause redundancy

Normalization

- Normalization is a method that **removes data redundancy** from a relation (minimizing the insertion, deletion and update anomalies that degrade the performance of databases)
- Normalization uses a series of tests (normal forms) to help identify the **optimal grouping for these attributes** to identify a set of suitable relations that supports the data requirements.
- examining the **functional dependencies** between attribute

Functional Dependency

- a relationship between two attributes in a relation (determinant, dependent)
  - ISBN -> BookTitle (ISBN determines the book title)
  - or
  - Employee_id → name job salary
  - or
  - street city→ postcode and
  - postcode →city

Armstrong’s axioms

- **Axiom of reflexivity**
  - If $Y \subseteq X$, then $X \longrightarrow Y$
  - (If Y is a subset of X, then X determines Y.)
- **Axiom of augmentation**
  - If $X \longrightarrow Y$, then $XZ \longrightarrow YZ$
  - (If X determines Y, then XZ determines YZ.)
- **Axiom of transitivity**
  - If $X \longrightarrow Y$ ja $Y \longrightarrow Z$, then $X \longrightarrow Z$
  - (If X determines Y and Y determines Z, then X must also determine Z.)

Why Functional Dependency?

- To define keys
  - *X = attributes never on the right hand side*
  - *Y = attributes both on the right hand and the left hand side*
  - *Z = attributes on the right hand never on the left hand side*
  - *X must be in every key, Y might be in a key, Z cannot be in any key*
- To normalize

- address(street, postcode, city)

- *address1(street, postcode)* and
- *address2(postcode, city)*

- inclusion dependency
  - *address1*[*postcode*] ⊆ *address2*[*postcode*]

Normalization and the “Forms”

- First Normal Form (1NF)
  - none of its domains have any sets as elements, attributes contains only single values from the domain (each column contains atomic values, and there are not repeating groups of columns)
- Second Normal Form (2NF)
  - 1NF+all non-key attributes are fully functional dependent on the primary key (the columns are dependent on the primary key)

Normalization and the “Forms”

- Third Normal Form (3NF)
  - 2NF+there is **no** transitive functional dependency (the columns are dependent on the primary key (2NF) and no other columns in the table)
    - *Student_id*, Student_name, Street, City, State, Zip
      - (Student_id as primary key)
    - But now Street, City, State are dependent on Zip not Student_id -> transitive functional dependency -> not in 3NF

Normalization and the “Forms”

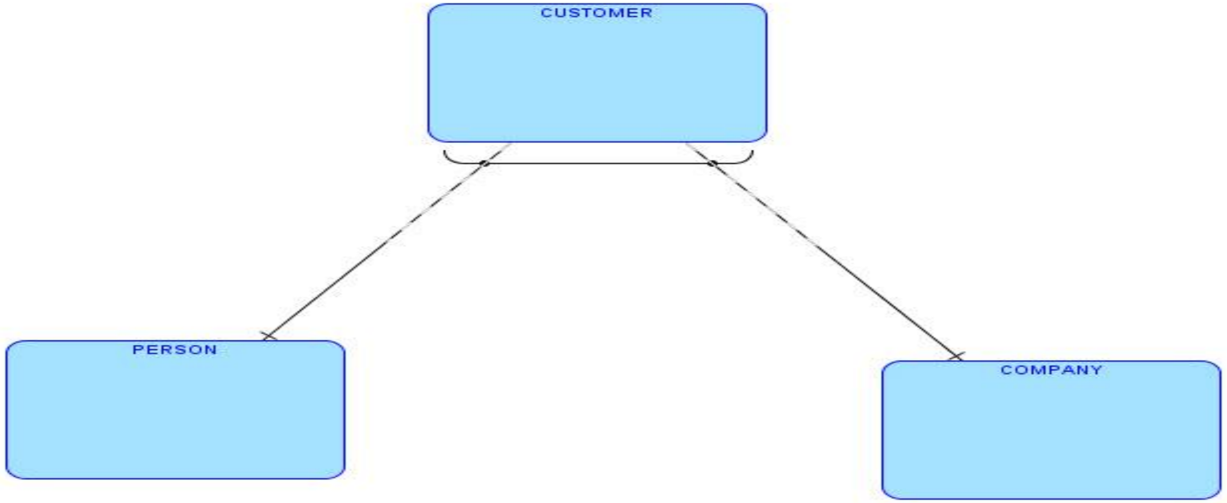
- Boyce–Codd Normal Form (BCNF)
  - Must be in 3NF and for each functional dependency (X -> Y), X should be a super Key.
  - if and only if there are no non-trivial functional dependencies of attributes on anything other than a superset of a candidate key. (Each attribute must represent a fact about the key, the whole key, and nothing but the key)
- Fourth Normal Form (4NF), Fifth Normal Form (5NF).

An entity, a relationship or an attribute?

- There are no foreign keys (and FK columns) in ER!
  - They are **relationships**
- An entity or an attribute?
  - Example, phonenumber (how many? Other attributes?)
- An entity or a relationship?
  - If it is a relationship in real world it is most likely a relationship in the data model too.

Specialization

- Specialization: A customer -> Person or Company



Specialization

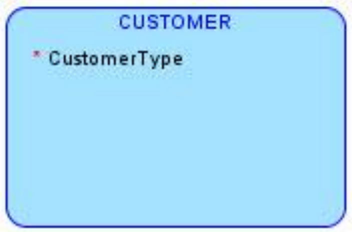
- Can Person change to a Company or vice versa?
- Do you always know which one the customer is?
- …

Generalization

- Generalization: A Vehicle (<- a car, a bus, a lorry, …)
  - A bus might have some attributes a car does not have etc. NULLs.
  - The Customer example:

Generalization

- Usually a discriminator to identify the ”type”



- Now only the attributes all the ”types” have can be defined mandatory and there will be penty on NULLs

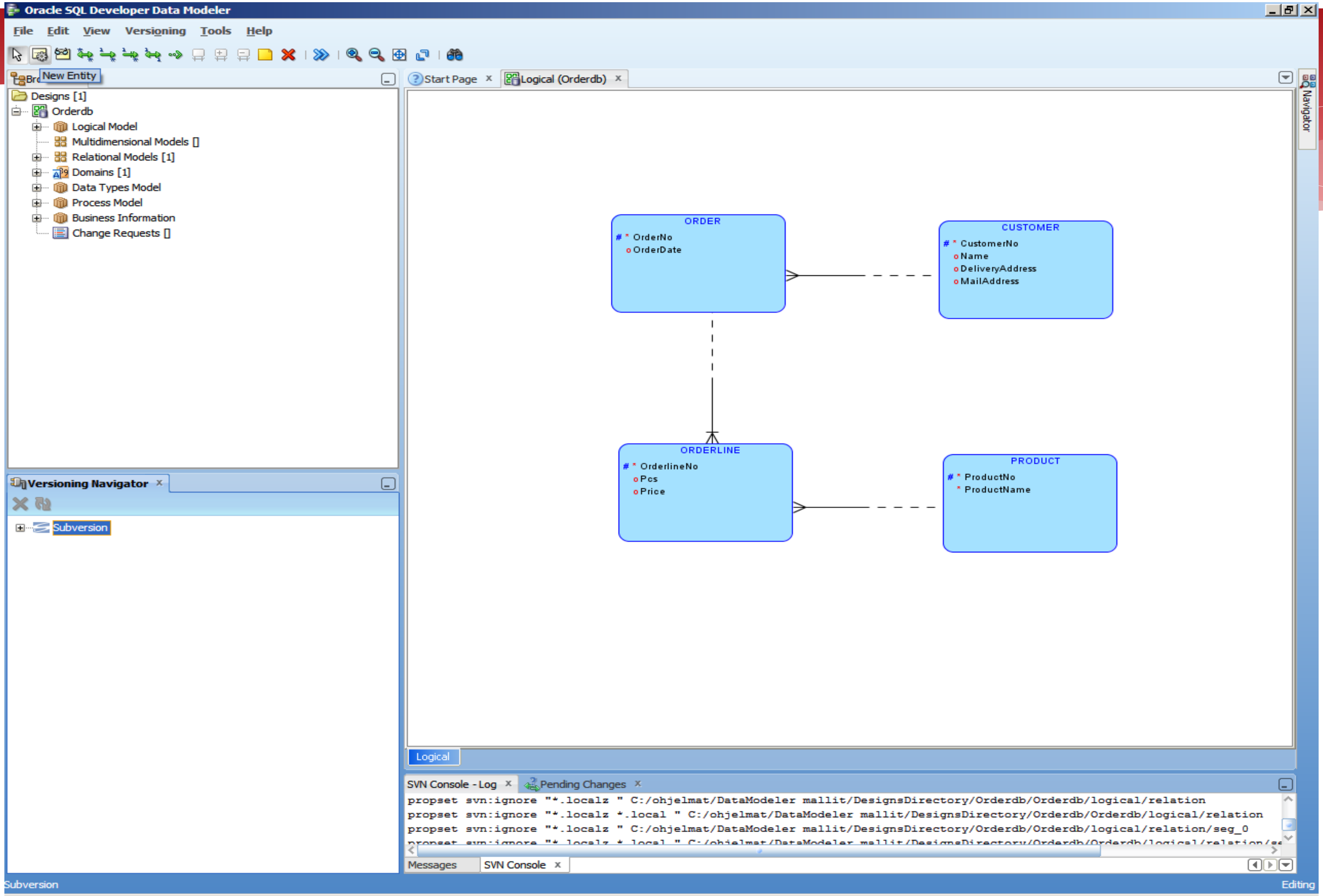
Specialization, generalization

- **Participation** constraint
  - Defines whether every member in the superclass must also be a member of a subclass or not
  - mandatory or optional
- **Disjoint** constraints
  - The disjoint constraint only applies when a superclass has more than one subclass. If the subclasses are disjoint, then an entity occurrence can be a member of only one of the subclasses.

Data Modeler

- Let’s design a database
- https://github.com/Mavihe1/DBworkshop

Testing the conceptual model



```
propset svn:ignore "*.localz " C:/ohjelmat/DataModeler mallit/DesignsDirectory/Orderdb/Orderdb/logical/relation
propset svn:ignore "*.localz *.local " C:/ohjelmat/DataModeler mallit/DesignsDirectory/Orderdb/Orderdb/logical/relation
propset svn:ignore "*.localz " C:/ohjelmat/DataModeler mallit/DesignsDirectory/Orderdb/Orderdb/logical/relation/seg_0
propset svn:ignore "*.localz *.local " C:/ohjelmat/DataModeler mallit/DesignsDirectory/Orderdb/Orderdb/logical/relation/se
```

Designing the database

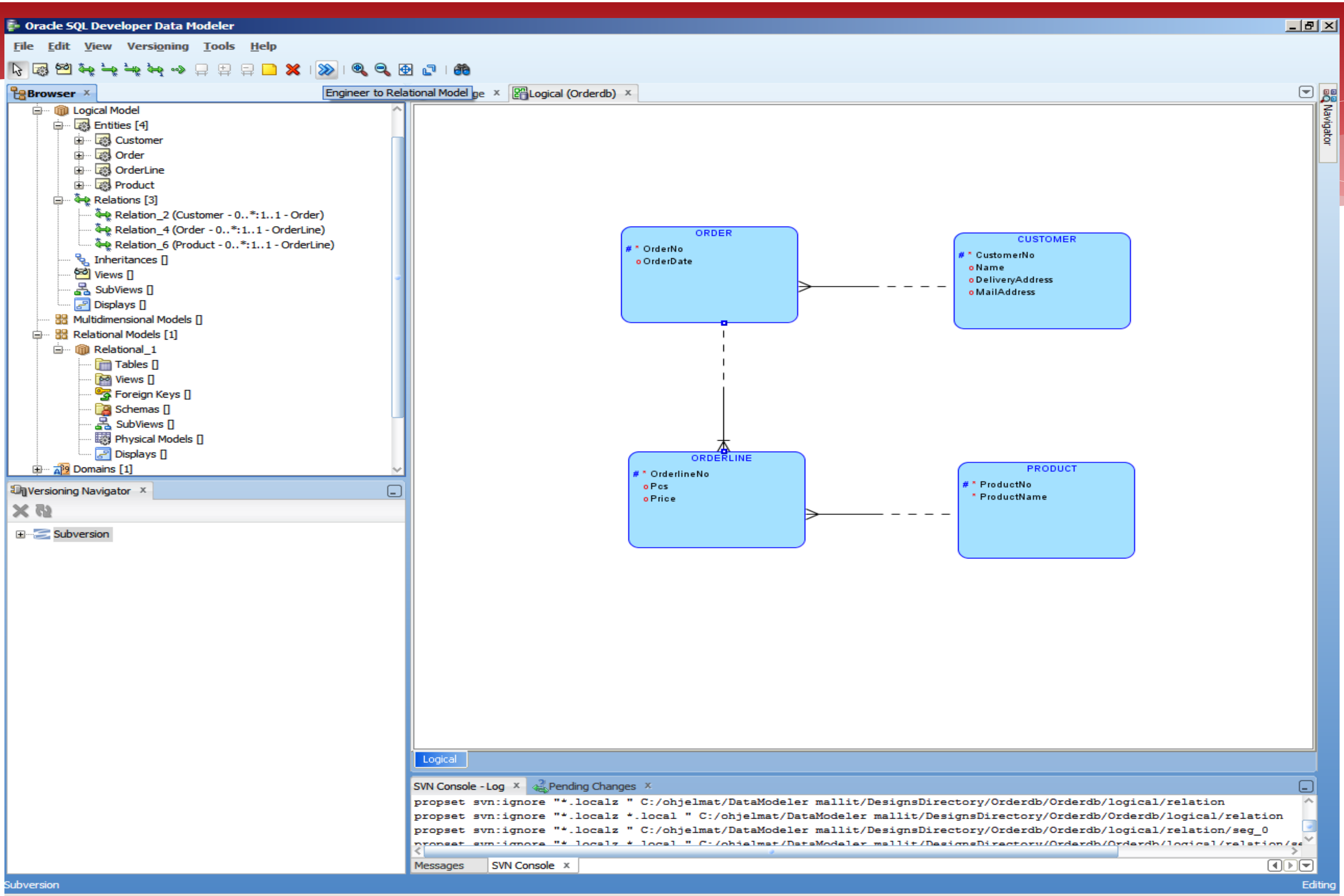
3. **Logical design:** transforming the conceptual model into a logical data model and a logical schema that the RDMS understands

Result: relational-database schema

(relational schemas and constraints)

To logical (relational) model

- The conceptual data model is refined and mapped to a logical data model.
- The logical data model defines the DBMS used
  - In our case relational data model for RDBMS
- But we do not define the ”brand” yet (Oracle, MySQL, MS SQL Server,…)
- The easiest is if you have a tool that automatically creates tables and foreign keys based on the ER



- Logical Model
  - Entities [4]
    - Customer
    - Order
    - OrderLine
    - Product
  - Relations [3]
    - Relation_2 (Customer - 0..*:1..1 - Order)
    - Relation_4 (Order - 0..*:1..1 - OrderLine)
    - Relation_6 (Product - 0..*:1..1 - OrderLine)
  - Inheritances []
  - Views []
  - SubViews []
  - Displays []
- Multidimensional Models []
- Relational Models [1]
  - Relational_1
    - Tables []
    - Views []
    - Foreign Keys []
    - Schemas []
    - SubViews []
    - Physical Models []
    - Displays []
- Domains [1]

```
propset svn:ignore "*.localz " C:/ohjelmat/DataModeler mallit/DesignsDirectory/Orderdb/Orderdb/logical/relation
propset svn:ignore "*.localz *.local " C:/ohjelmat/DataModeler mallit/DesignsDirectory/Orderdb/Orderdb/logical/relation
propset svn:ignore "*.localz " C:/ohjelmat/DataModeler mallit/DesignsDirectory/Orderdb/Orderdb/logical/relation/seg_0
propset svn:ignore "*.localz *.local " C:/ohjelmat/DataModeler mallit/DesignsDirectory/Orderdb/Orderdb/logical/relation/se
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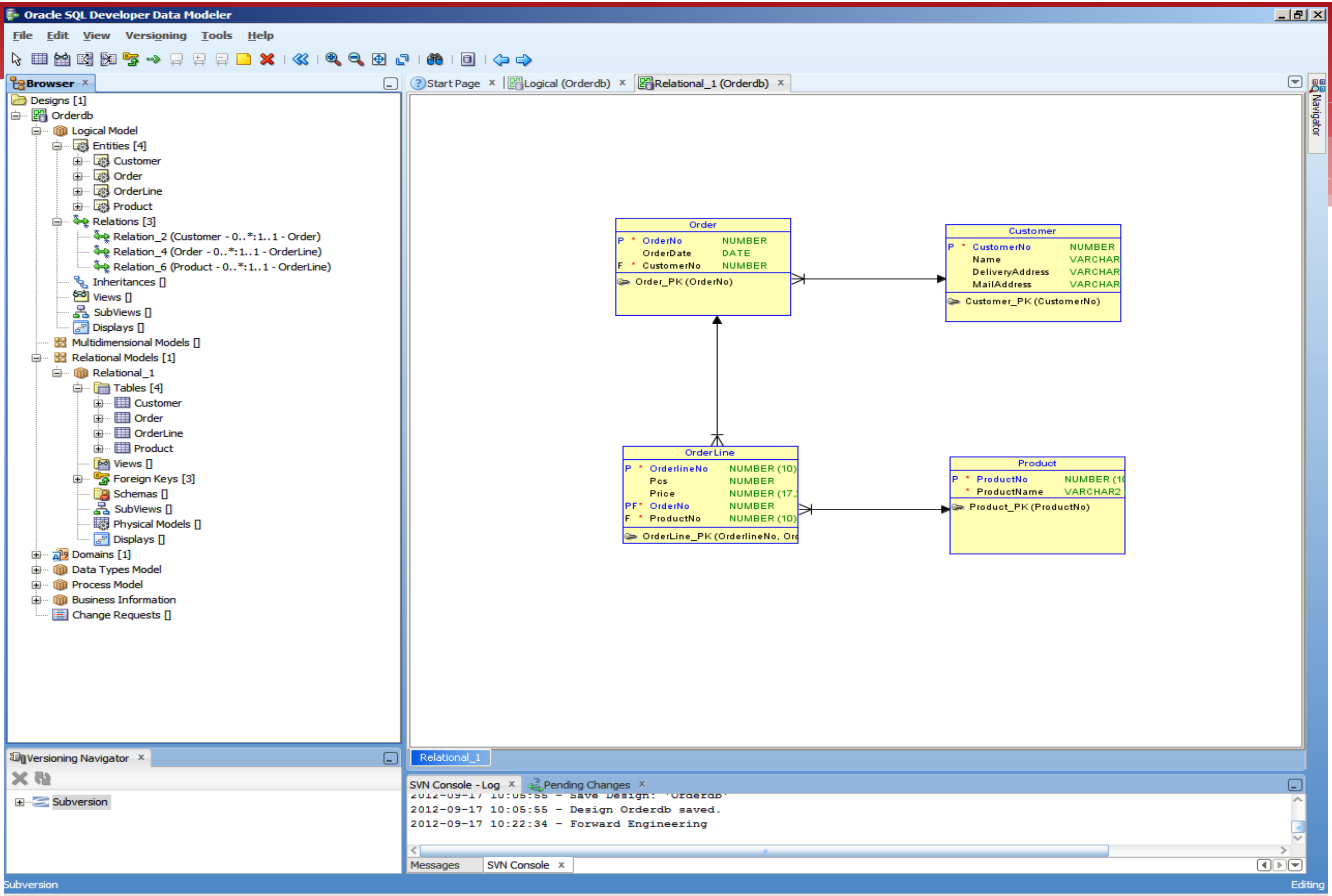
Relational model



Order		
P *	OrderNo	NUMBER
	OrderDate	DATE
F *	CustomerNo	NUMBER
	Order_PK (OrderNo)	

Customer		
P *	CustomerNo	NUMBER
	Name	VARCHAR
	DeliveryAddress	VARCHAR
	MailAddress	VARCHAR
	Customer_PK (CustomerNo)	

OrderLine		
P *	OrderlineNo	NUMBER (10)
	Pcs	NUMBER
	Price	NUMBER (17,
PF*	OrderNo	NUMBER
F *	ProductNo	NUMBER (10)
	OrderLine_PK (OrderlineNo, Orc	

Product		
P *	ProductNo	NUMBER (1
*	ProductName	VARCHAR2
	Product_PK (ProductNo)	

```
2012-09-17 10:05:55 - Save Design: 'Orderdb'
2012-09-17 10:05:55 - Design Orderdb saved.
2012-09-17 10:22:34 - Forward Engineering
```

Designing the database

4. **Physical design:** instances, tablespaces, indexes, disks …

And all of these phases over and over again…

(this is different, we have always done that but not so many times and in such a short cycles)

From relational to physical

- how the database will be implemented
- A specific DBMS system

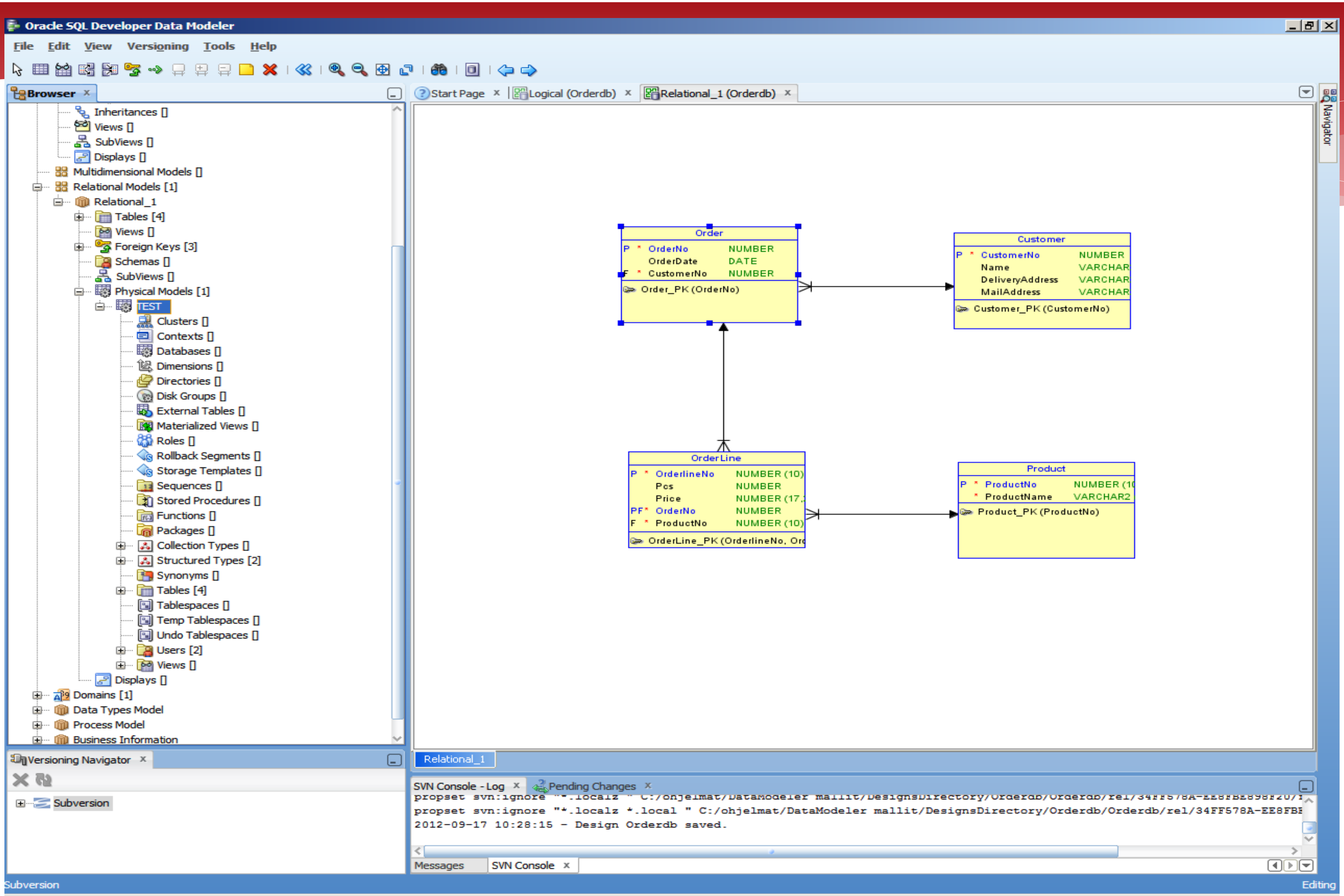
Physical design

- In short:
  - Start with the logical model
  - Design the disc usage, count the need for the space etc.
  - Indexes
  - Schemas
  - Tablespaces, storage definitions, user permissions,...

Physical design

- How, who and where to document?
- How to document any changes (patch, changes in database objects, ...)?
- Backup and recovery (test that is works every now and then!)

Physical model



```
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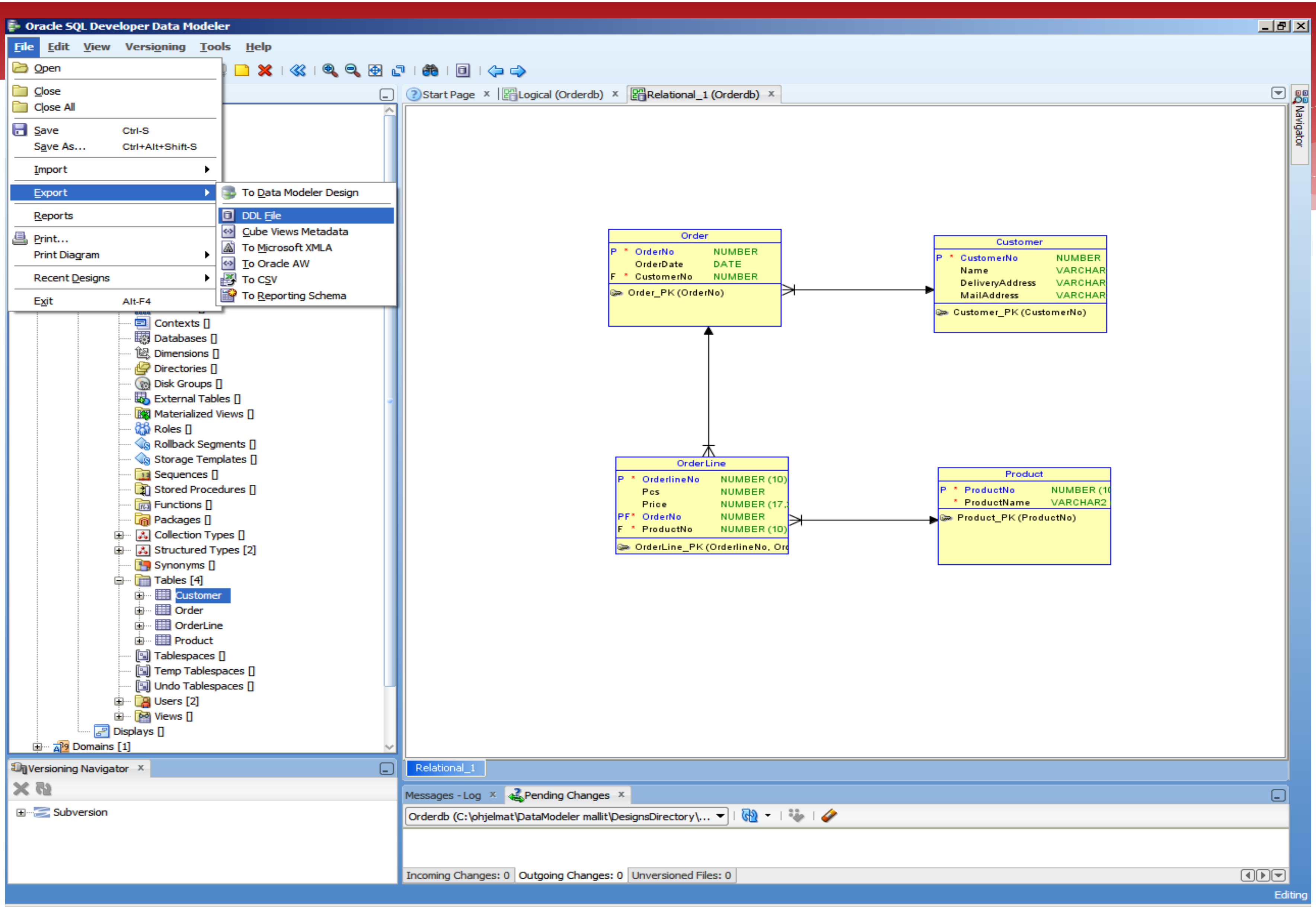
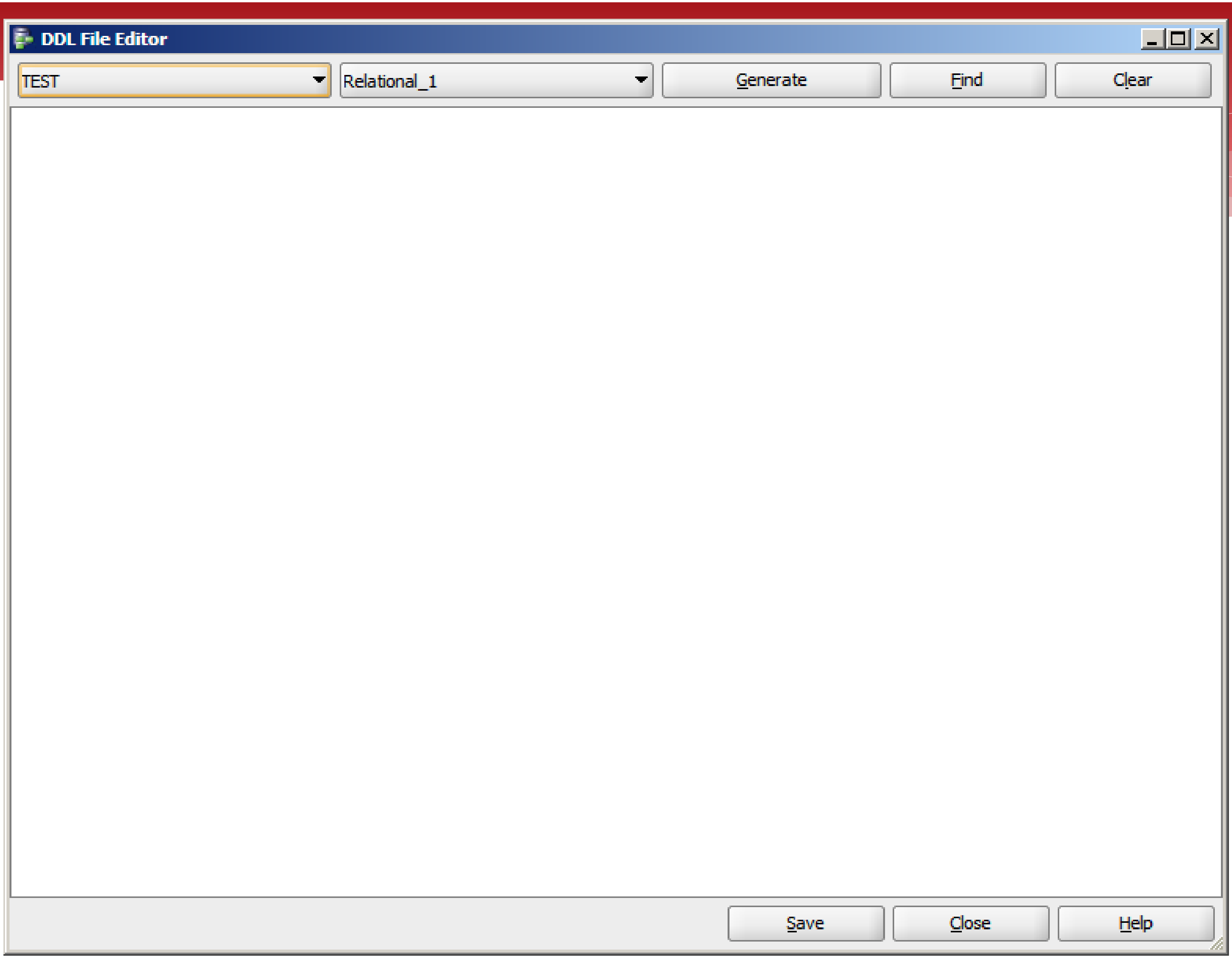
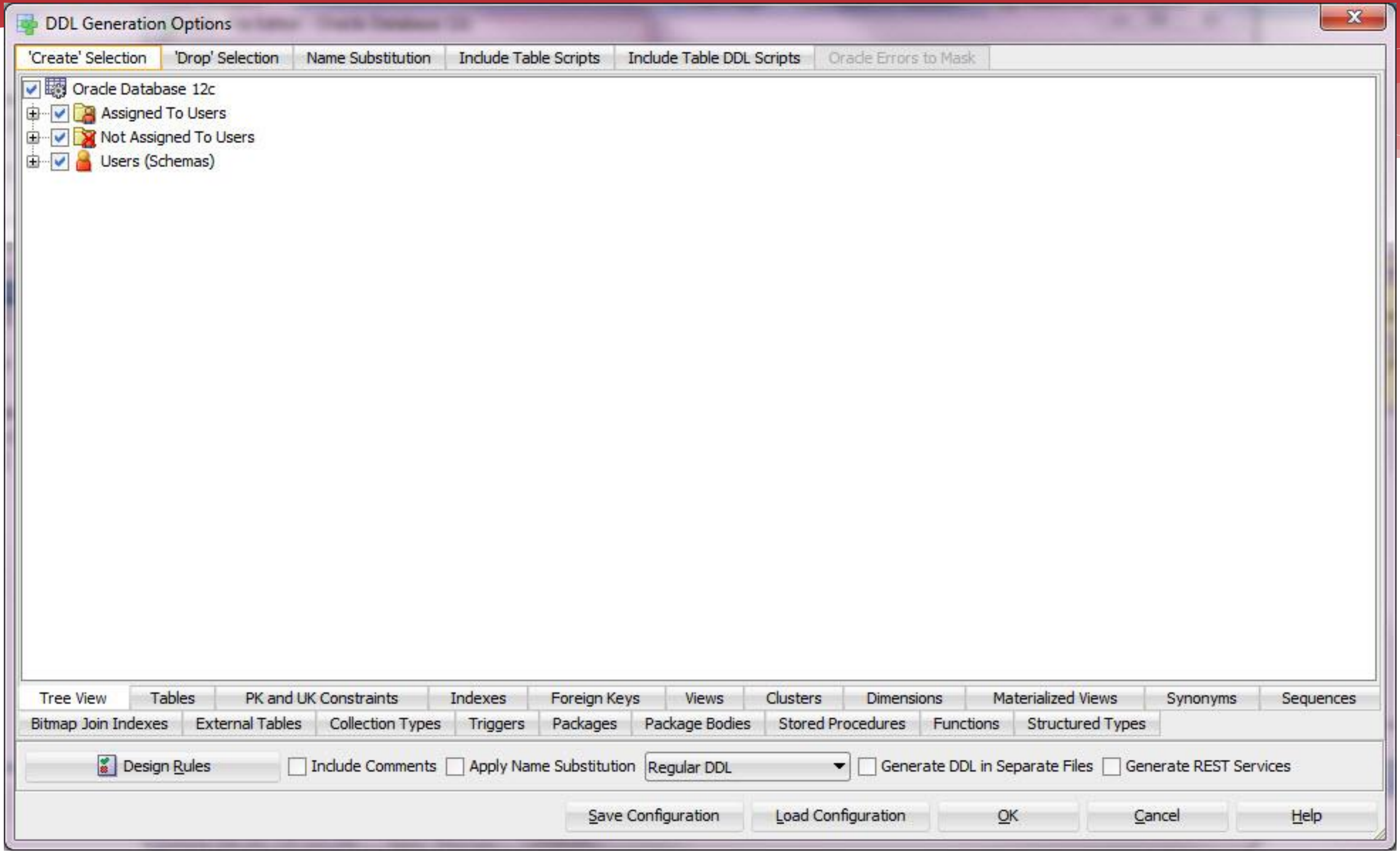
propset svn:ignore "*.localz *.local " C:/ohjelmat/DataModeler mallit/DesignsDirectory/Orderdb/Orderdb/rel/34FF578A-EE8FBE
2012-09-17 10:28:15 - Design Orderdb saved.
```

Implementation: Physical to DDLs


Oracle SQL Developer Data Modeler
File
Edit
View
Versioning
Tools
Help
Open
Close
Close All
Save Ctrl-S
Save As... Ctrl+Alt+Shift-S
Import
Export
Reports
Print...
Print Diagram
Recent Designs
Exit Alt-F4
To Data Modeler Design
DDL File
Cube Views Metadata
To Microsoft XMLA
To Oracle AW
To CSV
To Reporting Schema
Contexts []
Databases []
Dimensions []
Directories []
Disk Groups []
External Tables []
Materialized Views []
Roles []
Rollback Segments []
Storage Templates []
Sequences []
Stored Procedures []
Functions []
Packages []
Collection Types []
Structured Types [2]
Synonyms []
Tables [4]
Customer
Order
OrderLine
Product
Tablespaces []
Temp Tablespaces []
Undo Tablespaces []
Users [2]
Views []
Displays []
Domains [1]
Start Page
Logical (Orderdb)
Relational_1 (Orderdb)
Order
P * OrderNo NUMBER
OrderDate DATE
F * CustomerNo NUMBER
Order_PK (OrderNo)
Customer
P * CustomerNo NUMBER
Name VARCHAR
DeliveryAddress VARCHAR
MailAddress VARCHAR
Customer_PK (CustomerNo)
OrderLine
P * OrderlineNo NUMBER (10)
Pcs NUMBER
Price NUMBER (17,
PF* OrderNo NUMBER
F * ProductNo NUMBER (10)
OrderLine_PK (OrderlineNo, Or
Product
P * ProductNo NUMBER (1
* ProductName VARCHAR2
Product_PK (ProductNo)
Navigator
Relational_1
Versioning Navigator
Subversion
Messages - Log
Pending Changes
Orderdb (C:\ohjelmat\DataModeler mallit\DesignsDirectory\...
Incoming Changes: 0
Outgoing Changes: 0
Unversioned Files: 0
Editing

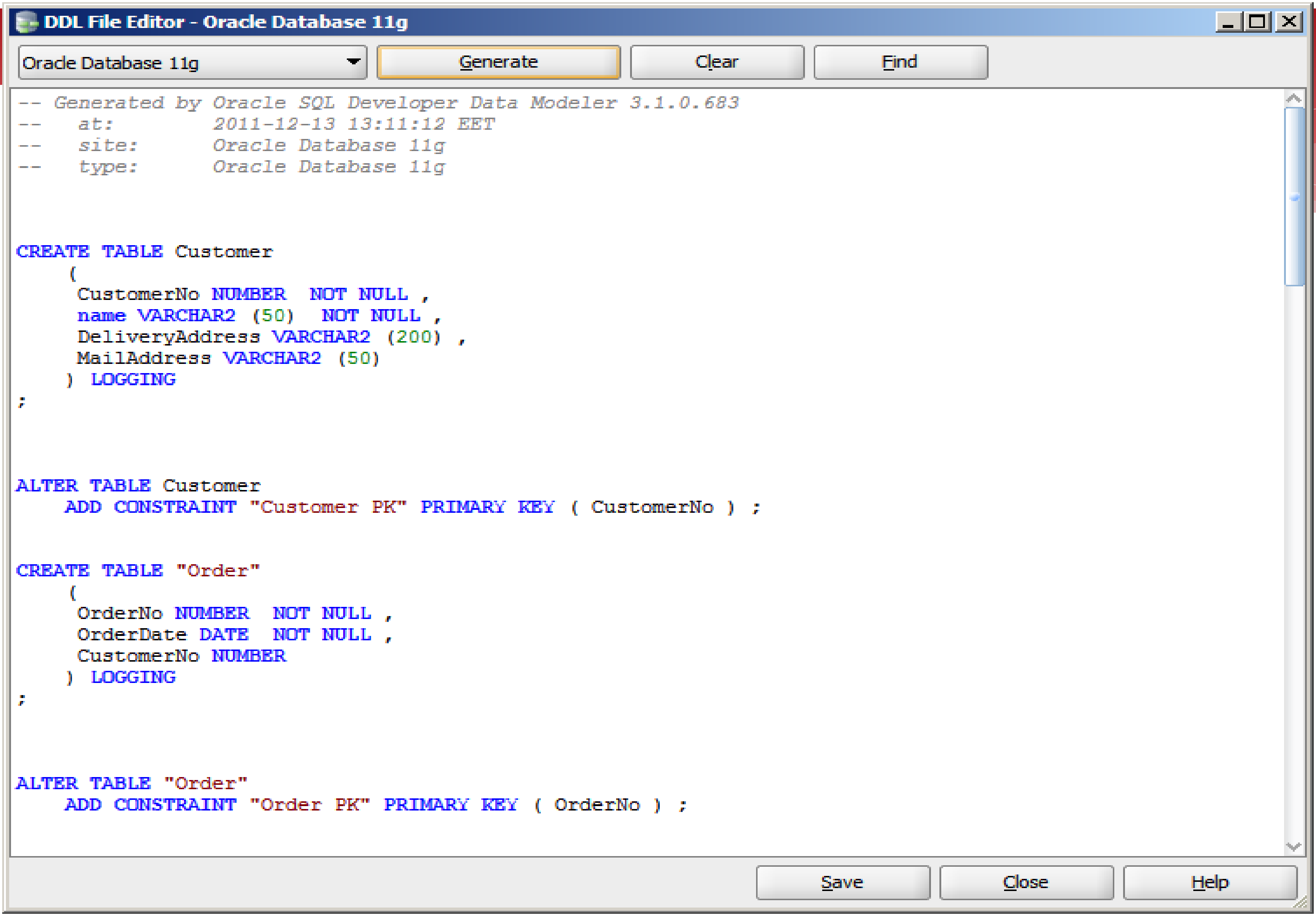


DDL File Editor
TEST
Relational_1
Generate
Find
Clear
Save
Close
Help



- ☑ Oracle Database 12c
  - ☑ Assigned To Users
  - ☑ Not Assigned To Users
  - ☑ Users (Schemas)

□ Include Comments □ Apply Name Substitution Regular DDL □ Generate DDL in Separate Files □ Generate REST Services



```
-- Generated by Oracle SQL Developer Data Modeler 3.1.0.683
--   at:        2011-12-13 13:11:12 EET
--   site:      Oracle Database 11g
--   type:      Oracle Database 11g



CREATE TABLE Customer
    (
     CustomerNo NUMBER  NOT NULL ,
     name VARCHAR2 (50)  NOT NULL ,
     DeliveryAddress VARCHAR2 (200) ,
     MailAddress VARCHAR2 (50)
    ) LOGGING
;



ALTER TABLE Customer
    ADD CONSTRAINT "Customer PK" PRIMARY KEY ( CustomerNo ) ;


CREATE TABLE "Order"
    (
     OrderNo NUMBER  NOT NULL ,
     OrderDate DATE  NOT NULL ,
     CustomerNo NUMBER
    ) LOGGING
;



ALTER TABLE "Order"
    ADD CONSTRAINT "Order PK" PRIMARY KEY ( OrderNo ) ;
```

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That was the process… but

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What kind of DB are you designing?

- Different rules for OLTP and DW
  - My ”own” data
  - Somebody else’s data

Maintenance

- Monitoring the performance of the system: tuning if needed.
- Maintaining and upgrading the database system.
- Maintaining the user privileges.
- Testing backups and recoveries.
- New requirements implemented using the design process.

Performance

- Plan, count, ...
- Test! With a real material (size, quality,...) and the right versions of program.

Tuning

- Hardware and operating system
- DBMS
- Model level (logical, physical, transaction)
- All three levels affect each others

Indexing

- Select **might** be faster
- Insert, Update, Delete slower
- Not a silver bullet

Tuning the queries

- Transform the query to a more efficent form (**execution plan**) with the same outcome (**result**) than the original query (**equivalent**).

Tuning, the process

- Ask direct questions. (”Nothing is working” is not an answer)
- Be systematic and find the real problem
- Solve the problem
- Document the problem and the solution (new problems because of the solution?)

Refactoring the database

- Analyze the change from the **database** perspective
  - The phase of the database, development vs production
  - The phase of usage of the database, development vs production
  - Completely new database vs ”old” database
- Analyze the change from the **project** perspective (cheep coding now is not an excuse for a bad database design)

Refactoring the database

- Analyze the change from the **maintenance** point of view (would it be more clear to call discount DISCOUNT than AMOUNT?)
- Versioning
- Always remember somebody will maintain this system and this database
- Always remember clear and understandable solutions, do not try to be too clever

Refactoring the database

- The problems related to refactoring the database usually have nothing to do with the database but everything to do ”on top” of the database
- Refactoring the database is nothing special, just normal database design process

A tool

Oracle SQL Developer Data Modeler

- To be efficient in designing you need a tool: my recommendation is Data Modeler
  - Free of charge
  - Support for many different databases
  - Support for both documenting the existing databases and designing a new one (and mainintaining that)
  - Support for reporting, naming standards, glossaries, design rules, ...
  - Support for version control and multiuser environment
  - Support for everything you need for database design plus more

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Conclusions

- Database designing is an important work
- The database must be designed and for the right purpose .
- Data integrity and data quality must be the guiding rules.
- 3NF or Boyce-Codd preferred

Conclusions

- You need a tool!
- Data Modeler is a good tool; good support for iterative processes
- Enables documenting and versioning (and comparing the versions)
- Enables multiuser environment
- Is free to use
- Support for other databases as well

THANK YOU!

QUESTIONS?

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