DataBases
2022/23

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Software Engineering Dept.
Computer Science Faculty

Организация курса

Repository: https://bitbucket.org/adbadb/db-dsba-22
Telegram: https://t.me/+2CCPjiPs_JA0NDE6
Assignments: https://canvas.instructure.com/enroll/3WN9W9

Cumulative grade (70% of final grade)

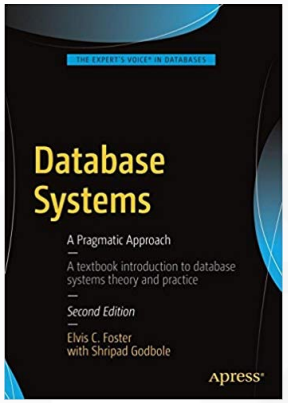
- Seminar work 20%
- Homework/group project 40%
- Essay 20%
- Quizzes 10%
- Midterm 10%

Exam (30% of final grade)

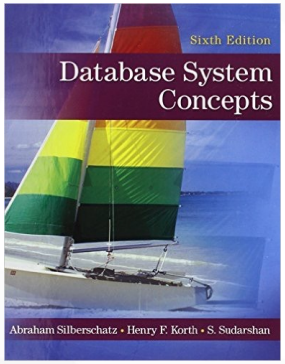
Auto grade: max(cumulative, 8)

Textbooks

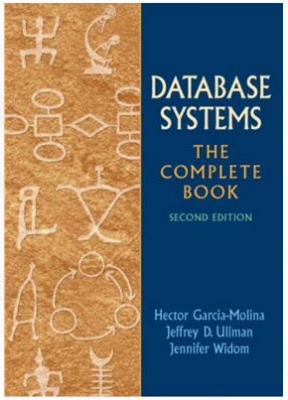
Foster, E. C., Godbole S.
Database Systems: A Pragmatic Approach,
2nd ed., 2016



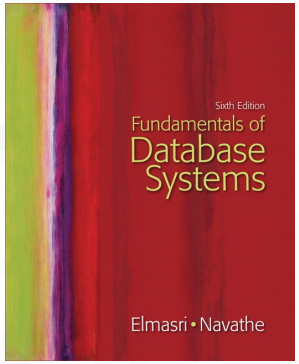
Silberschatz A., Korth H.F., Sudarshan S.
Database System Concepts
6th ed, McGraw-Hill, 2010.



Garcia-Molina H., Ullman J., Widom J.
Database Systems: The Complete Book
2nd ed, Prentice Hall, 2009.



Elmasri R., Navathe S.B.
Fundamentals of Database Systems
6th ed., Addison Wesley, 2010.



Course structure

User perspective

- how to use a database system?
- conceptual data modeling, the relational and other data models, database schema design, relational algebra, SQL query language, object-relational mappings, application design and implementation

System perspective

- how to design and implement a database system?
- data representation, indexing, query optimization and processing, transaction processing, concurrency control, crash recovery

Project: Database-driven information system

1. Form a team of 1 to 5 students
2. Identify an application domain that requires a DB (for desktop/web/mobile access)
3. Define requirements for application (IEEE 830)
4. Design the relational DB (E/R, UML, SQL DDL)
5. Design the application
6. Implement database and application
7. Prepare a report and presentation

- use **relational** database management system: Oracle Database, MS SQL Server, IBM DB2, MySQL, PostgreSQL, etc.
- use **any programming language you** prefer: Java, Python, Ruby, C, C++, C#, Erlang, Go, PHP, etc.

Overview

1st Module

- Introduction
- Data modeling
- Database design: E/R and UML
- Relational model
- Relational database design
- Relational query languages
- SQL: Querying
- SQL: Updating
- SQL: Data Definition

2nd Module

- Application design and development
- Storage and file structure
- Indexing and Hashing
- Query processing
- Transaction management

- Projects presentations

History of Data Management

Stone Age (- 1970)

-1900: Manual processing

1900-1955: Mechanical punched cards processing

1955-1970: Stored programs - sequential records processing

Age of Transactions (1970 -)

Goal: reliability - make sure no data is lost

1960s: IMS (hierarchical data model)

1980s: Oracle (relational data model)

Age of Business Intelligence (1995 -)

Goal: analyze the data -> make business decisions

Aggregate data for boss. Tolerate imprecision!

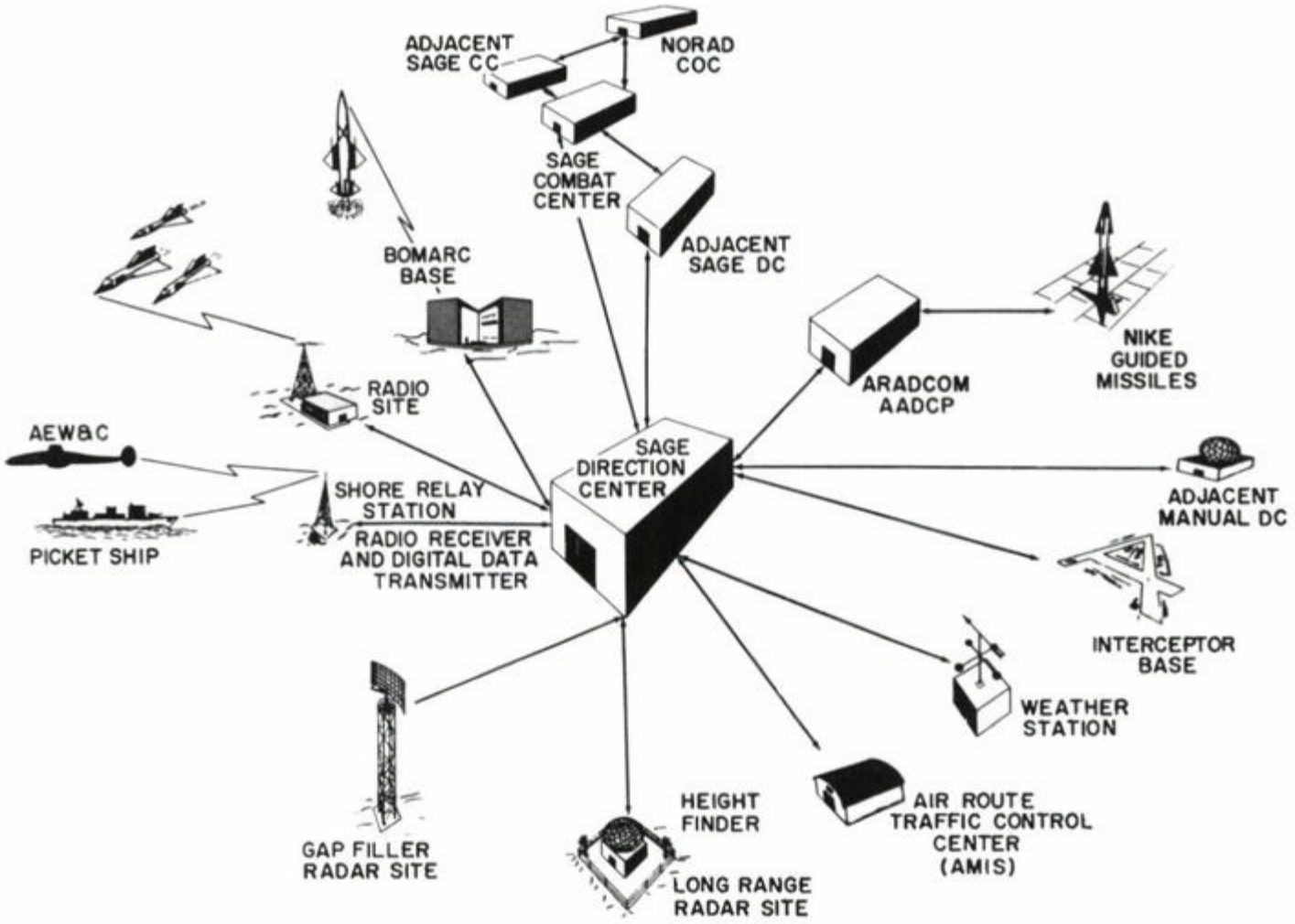
SAP BW / Business Objects, Cognos, …, Essbase

Age of „Big Data “ and „Data for the Masses“ (2000-)

Goal: everybody has access to everything

Google (text), Cloud (XML, JSON: Services)

The very first database: SAGE (1957-1983)



History of Data Management Repeats Itself

- Old database issues are still relevant today
- The “SQL vs NoSQL” debate is reminiscent of “Relational vs CODASYL” debate
- Many of the ideas in modern database systems are not new

History of Data Management: IBM IMS (1960s)

IBM IMS – first database system developed to keep track of purchase orders for Apollo moon mission.

- Hierarchical data model.
- Programmer-defined physical storage format.
- Tuple-at-a-time queries.

Hierarchical Data Model

Schema

SUPPLIER
(sno, sname, scity, sstate)

PART
(pno, pname, psize, qty, price)

Instance

sno	sname	scity	sstate	parts
1001	Dirty Rick	New York	NY	
1002	Squirrels	Boston	MA	

pno	pname	psize	qty	price
999	Batteries	Large	10	$100

pno	pname	psize	qty	price
999	Batteries	Large	14	$99

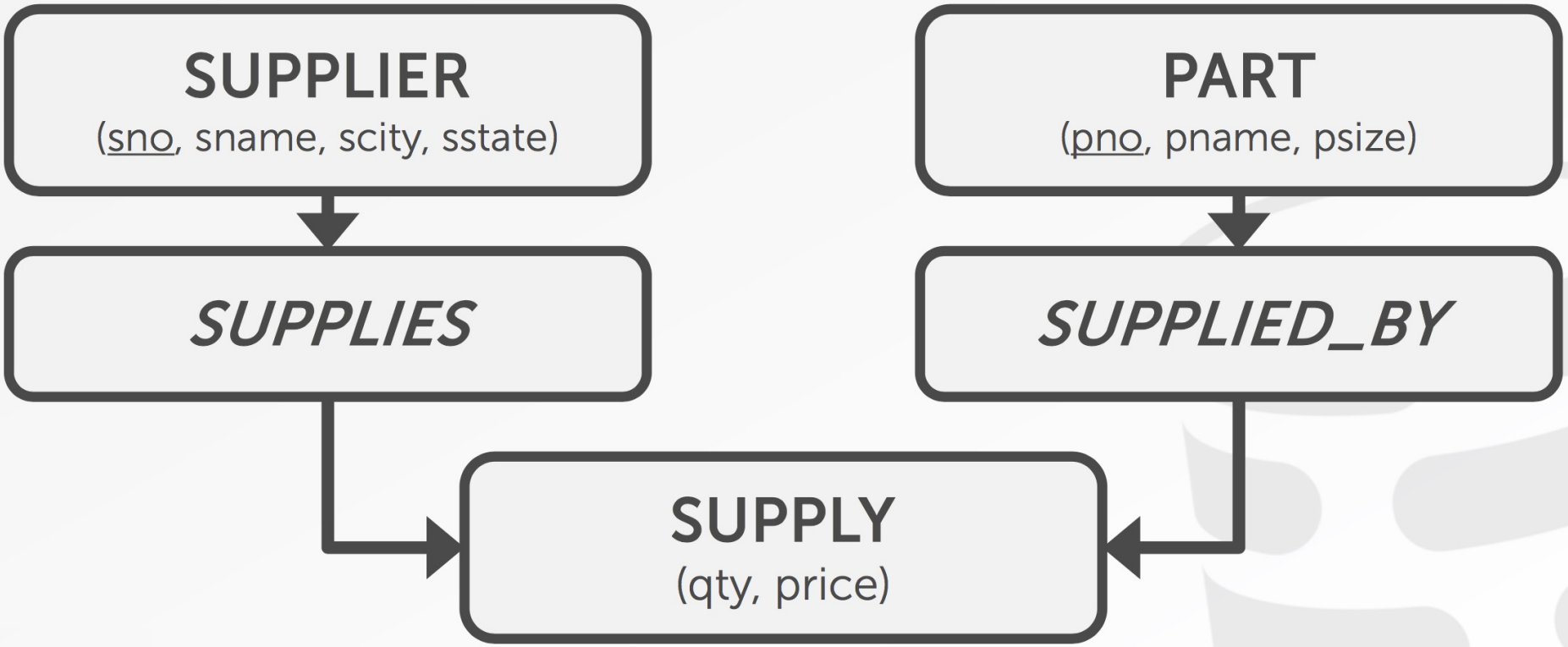
History of Data Management: CODASYL (1960s-1970s)

COBOL people got together and proposed a standard for how programs will access a database. Lead by Charles Bachman.

- Network data model.
- Tuple-at-a-time queries.

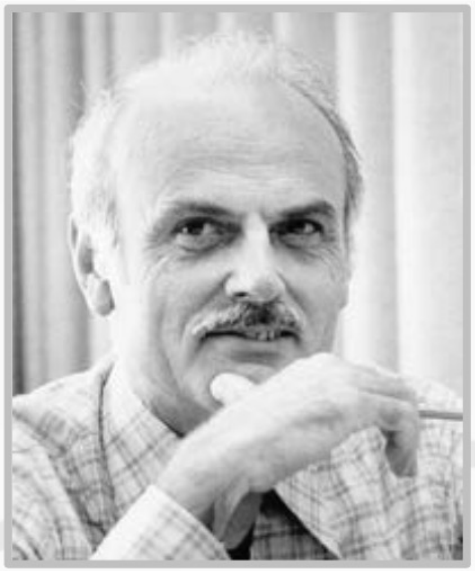
Network Data Model

Schema



History of Data Management: Relational (1960s-1970s)

Ted Codd was a mathematician working at IBM Research. He saw developers spending their time rewriting IMS and CODASYL programs every time the database's schema or layout changed.

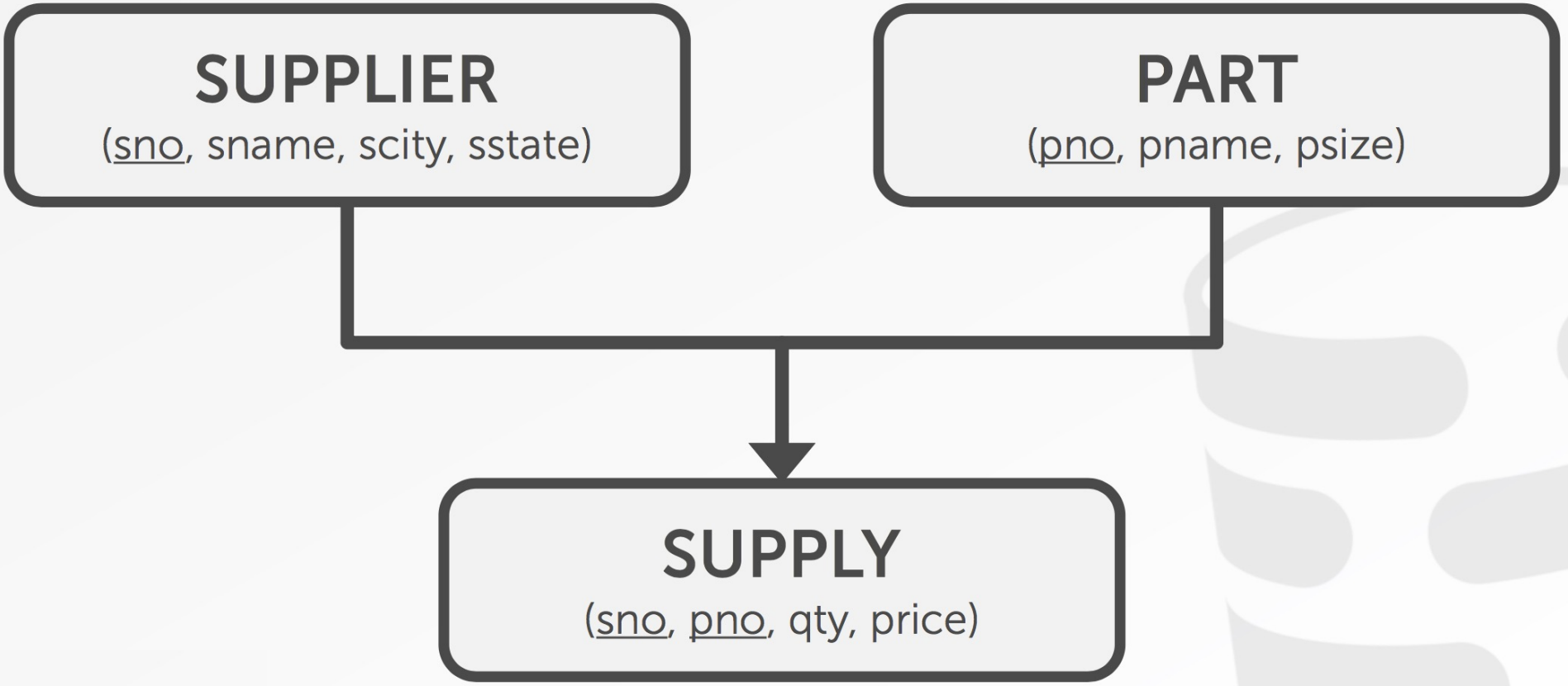


Database abstraction to avoid this maintenance:

- Store database in simple data structures.
- Access data through high-level language.
- Physical storage left up to implementation.

Relational Data Model

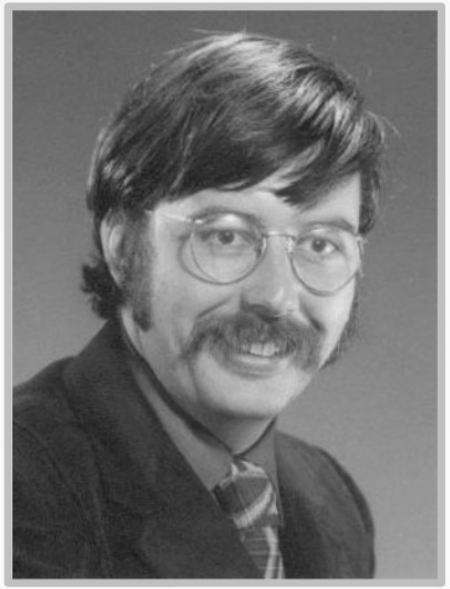
Schema



Relational Data Model

Early implementations of relational DBMS:

- **System R** – IBM Research
- **INGRES** – U.C. Berkeley
- **Oracle** – Larry Ellison



History of Data Management: Relational (1970s-1980s)

The relational model wins.

- IBM comes out with DB2 in 1983.
- "SEQUEL" becomes the standard (SQL).

Many new "enterprise" DBMSs but Oracle wins marketplace.

Stonebraker creates Postgres.

History of Data Management: Object-Oriented (1980s)

- Avoid “relational-object impedance mismatch” by tightly coupling objects and database.
- Few of these original DBMSs from the 1980s still exist today but many of the technologies exist in other forms (JSON, XML)

History of Data Management: Object-Oriented (1980s)

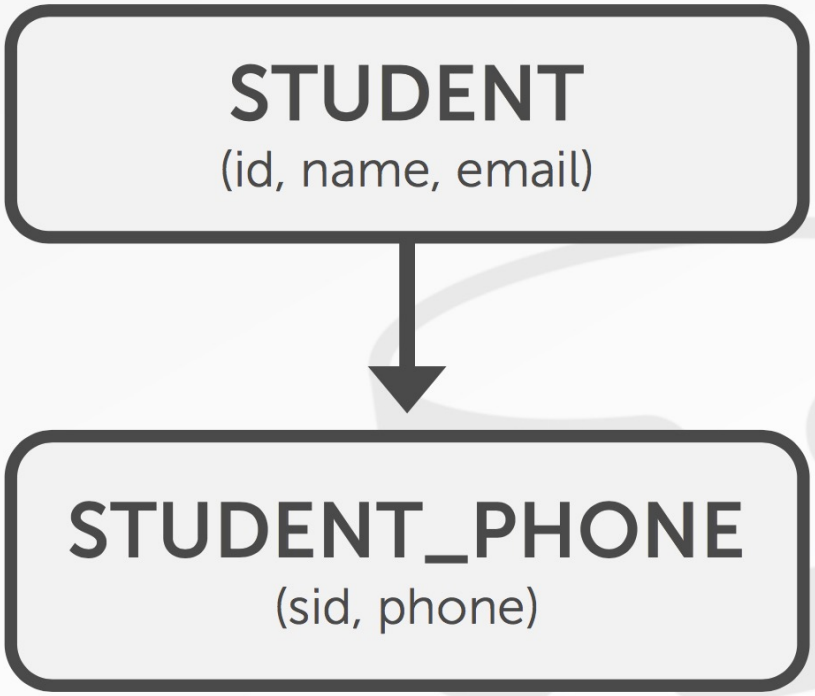
Application Code

```
class Student {
    int id;
    String name;
    String email;
    String phone[];
}
```

id	name	email
1001	M.O.P.	ante@up.com

sid	phone
1001	444-444-4444
1001	555-555-5555

Relational Schema



History of Data Management: Object-Oriented (1980s)

Application Code

```
class Student {
    int id;
    String name;
    String email;
    String phone[];
}
```

Student

```
{
  "id": 1001,
  "name": "M.O.P.",
  "email": "ante@up.com",
  "phone": [
      "444-444-4444",
      "555-555-5555"
   ]
}
```

History of Data Management: Boring Years (1990s)

No major advancements in database systems or application workloads.

- Microsoft forks Sybase and creates SQL Server.
- MySQL is written as a replacement for mSQL.
- Postgres gets SQL support.

History of Data Management: Internet Boom(2000s)

- All the big players were heavyweight and expensive. Open-source databases were missing important features.
- Many companies wrote their own custom middleware to scale out database across single-node DBMS instances.

History of Data Management: Data Warehouses (2000s)

Rise of the special purpose OLAP DBMSs.

- Distributed / Shared-Nothing
- Relational / SQL
- Usually closed-source.

Significant performance benefits from using Decomposition Storage Model (i.e., columnar)

Vertica, Netezza, Greenplum, ParAccel, DATAllegro

History of Data Management: NoSQL Systems (2000s)

Focus on high-availability & high-scalability:

- Schemaless (i.e., “Schema Last”)
- Non-relational data models (document, key/value, etc)
- No ACID transactions
- Custom APIs instead of SQL
- Usually open-source

MongoDB, Cassandra, Redis, Riak, Aerospike, Neo4J, RethinkDB, DynamoDB, HBase, CouchDB, CouchBase

History of Data Management: NewSQL Systems (2000s)

Provide same performance for OLTP workloads as NoSQL DBMSs without giving up data consistency

- Relational / SQL
- Distributed
- Usually closed-source

SAP HANA, VoltDB, NuoDB, MemSQL, H-Store, dbShards, Clustrix, ScaleArc, HyPer, JustOne DB

History of Data Management: Hybrid Systems (2010s)

Hybrid **T**ransactional-**A**nalytical **P**rocessing.

Execute fast OLTP like a NewSQL system while also executing complex OLAP queries like a data warehouse system.

- Distributed / Shared-Nothing
- Relational / SQL
- Mixed open/closed-source.

SAP HANA, MemSQL, HyPer, JustOne DB, Snappy, Splice Machin

History of Data Management

There are many innovations that come from both industry and academia:

- Lots of ideas start in academia but few build complete DBMSs to verify them.
- IBM was the vanguard during 1970-1980s but now Google is current trendsetter.
- Oracle borrows ideas from anybody.

The relational model has won for operational databases.

Database Example

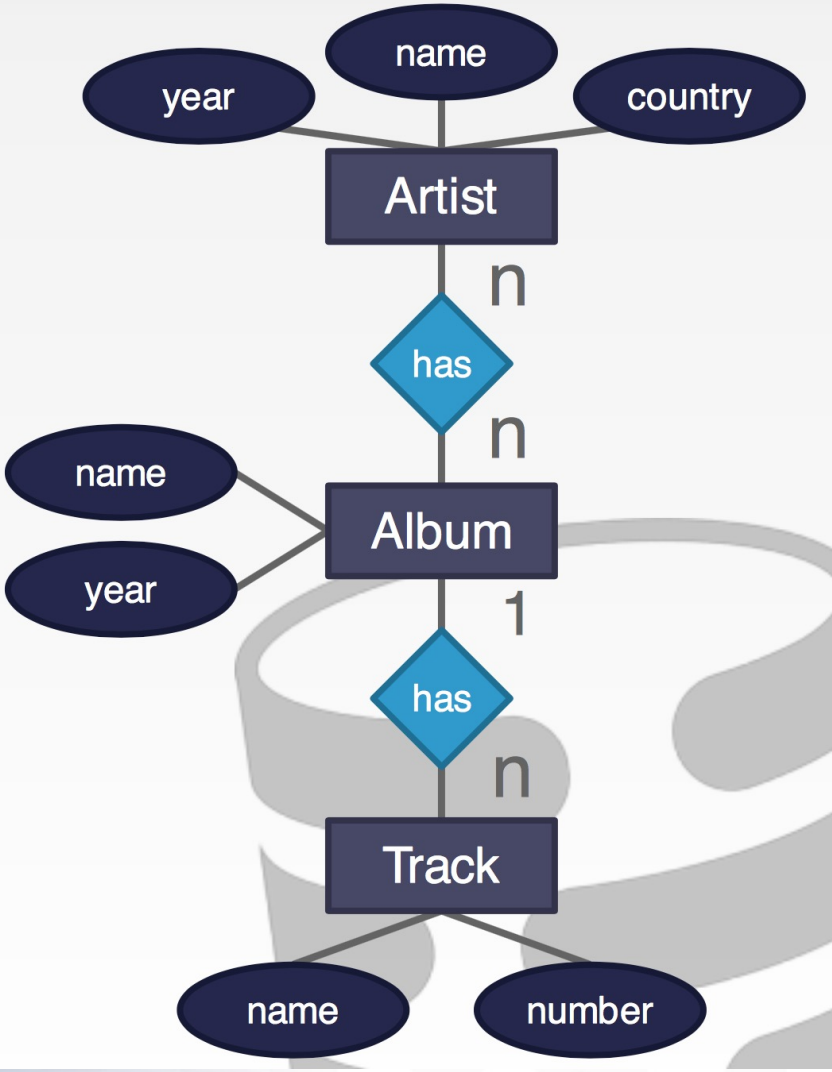
Create a database that models a digital music store.

Things we need to store:

- Information about Artists
- Albums released by Artists
- The Tracks on those Albums

Entity-Relationship Diagram

- Artists have names, year that they started, and country of origin.
- Albums have names, release year.
- Tracks have a name and number.
- An Album has one or more Artists.
- An Album has multiple Tracks.
- A Track can appear only on one Album.



Flat File Data Storage

Store the data in comma-separated value (CSV) files.

- Use a separate file per entity.
- The application has to parse the files each time they want to read/update records.

Artist(name, year, country)

```
"Wu Tang Clan",1992,"USA"
"Notorious BIG",1992,"USA"
"Ice Cube",1989,"USA"
```

Album(name, artist, year)

```
"Enter the Wu Tang","Wu Tang Clan",1993
"St.Ides Mix Tape","Wu Tang Clan",1994
```

Flat Files: Data Integrity, API, Durability

Data Integrity

- How do we ensure that the artist is the same for each album entry?
- What if somebody overwrites the album year with an invalid string?
- How do we store that there are multiple artists on an album?

API

- How do you find a particular record?
- What if we now want to create a new application that uses the same database?
- What if two threads try to write to the same file at the same time?

Durability

- What if the machine crashes while we're updating record?
- What if we want to replicate the database on multiple machines for high availability?

Database Management System (DBMS)

System for providing
EFFICIENT,
CONVENIENT and
SAFE
MULTI-USER storage of and access to
MASSIVE amounts of
PERSISTENT data

Why not direct implementation?

Storing data: file system is limited

- size limit by disk or address space
- when system crashes we may loose data
- password/file-based authorization insufficient

Query/update:

- need to write a new C++/Java program for every new query
- need to worry about performance

Concurrency: limited protection

- need to worry about interfering with other users
- need to offer different views to different groups of users

Schema change:

- entails changing file formats
- need to rewrite virtually all applications

More requirements for DBMS

SAFE:

from system failures

from malicious users

CONVENIENT:

simple commands to - debit account, get balance, etc.

unpredicted queries should also be easy

EFFICIENT:

don't search all files in order to get balance of one account

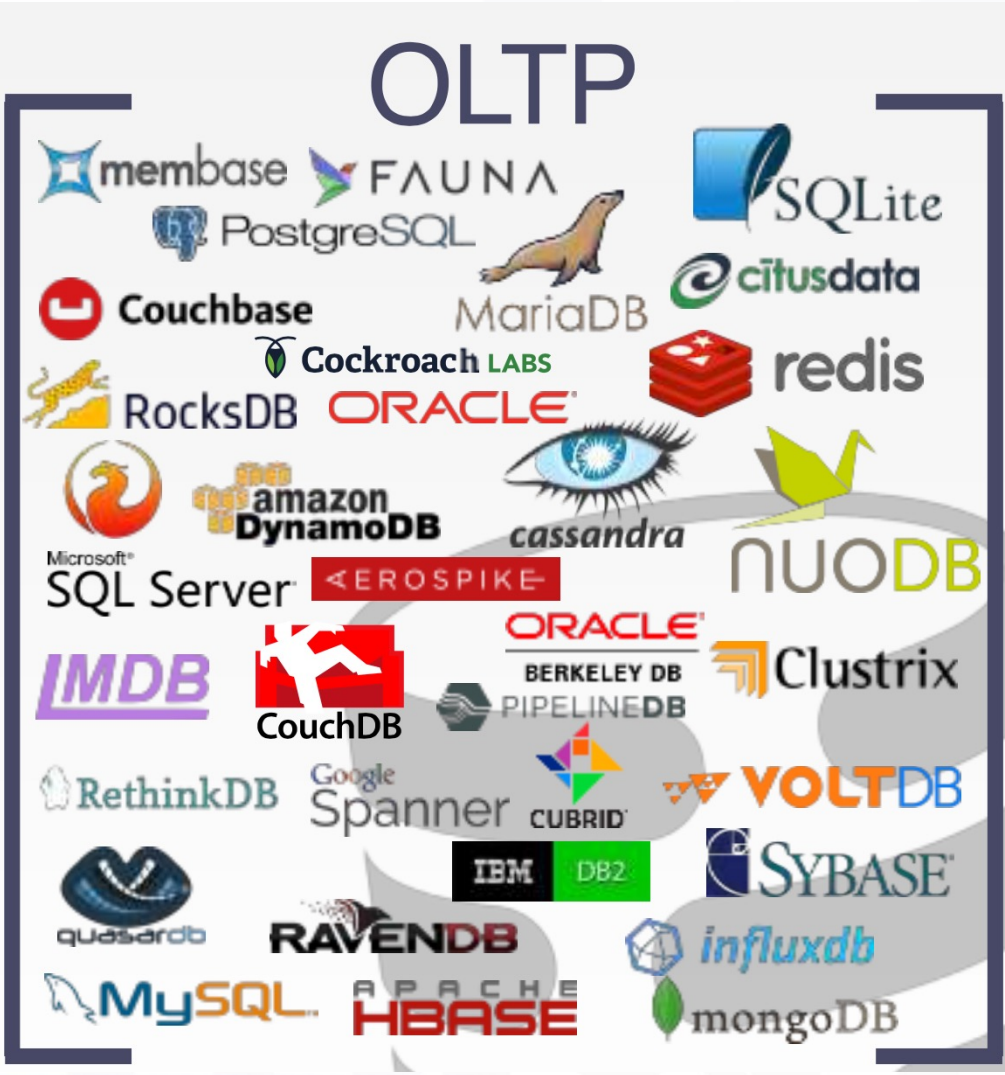
also: get all accounts with low balances, get large transactions, etc.

massive data! -> carefully tune DBMS for performance

DBMS Workload Types: OLTP

On-line Transaction Processing

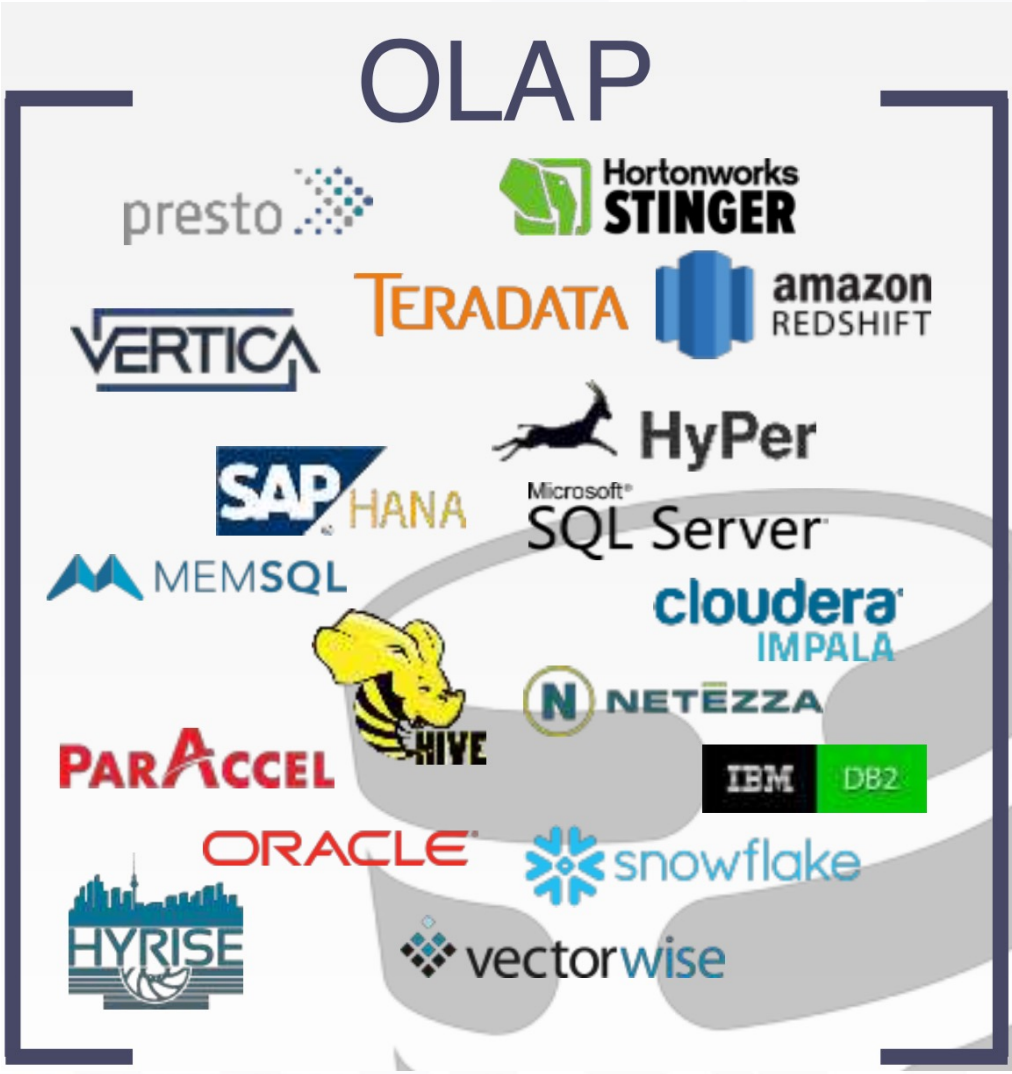
- Fast operations that only read/update a small amount of data each time.



DBMS Workload Types: OLTP, OLAP, HTAP

On-line Transaction Processing
- Fast operations that only read/update a small amount of data each time.

On-line Analytical Processing
- Complex queries that read a lot of data to compute aggregates.

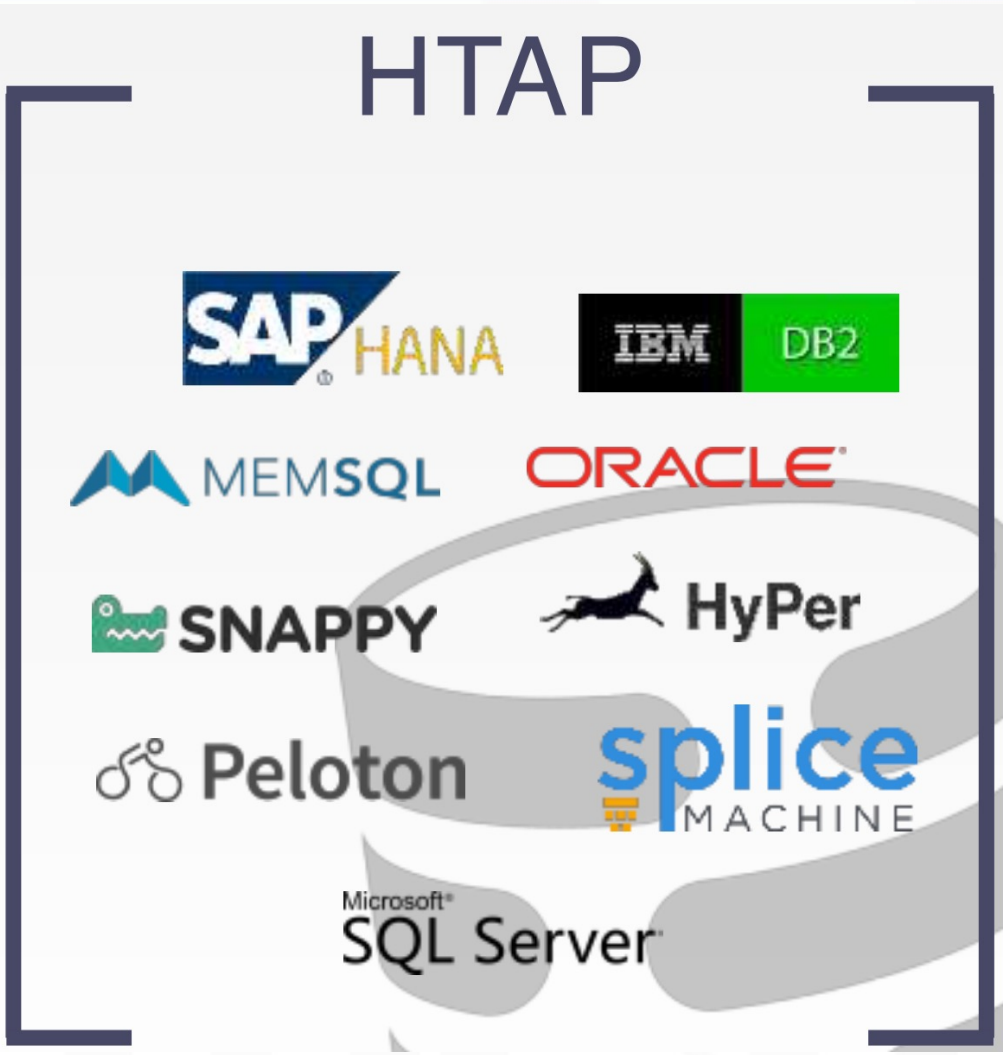


DBMS Workload Types: OLTP, OLAP, HTAP

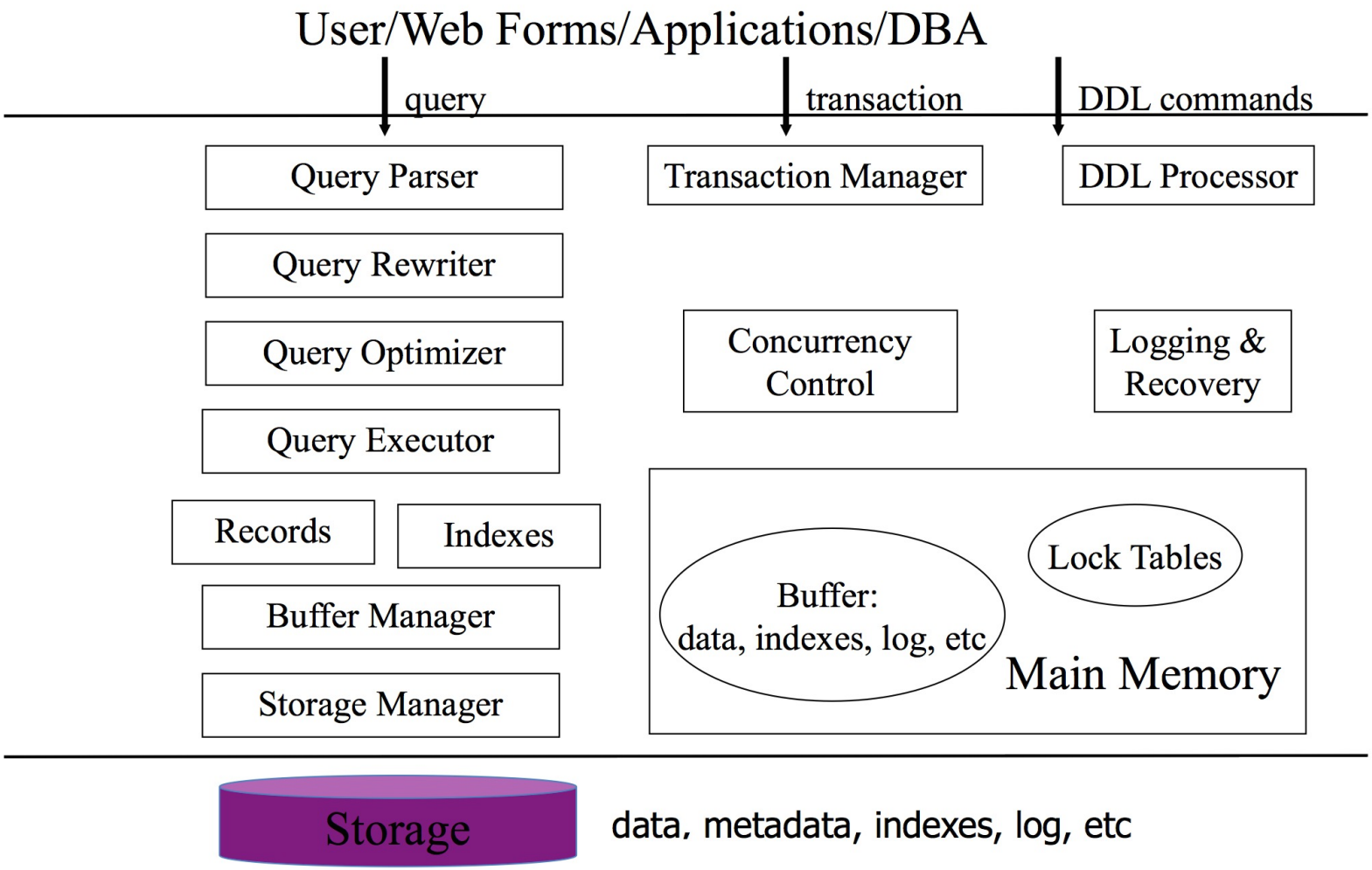
On-line Transaction Processing
- Fast operations that only read/update a small amount of data each time.

On-line Analytical Processing
- Complex queries that read a lot of data to compute aggregates.

Hybrid Transaction + Analytical Processing
- OLTP+OLAP together on the same database instance



DBMS Internals



Data structuring: model, schema, data

Data model:

conceptual structuring of data stored in database

ex: data is set of records, each with student-ID, name, address, courses, photo

ex: data is graph where nodes represent cities, edges represent airline routes

Schema versus data

schema: describes how data is to be structured

defined at setup time, rarely changes (also called "metadata")

data is actual "instance" of database, changes rapidly

vs. types and variables in programming languages

Data definition language (DDL)

commands for setting up schema of database

Data manipulation language (DML)

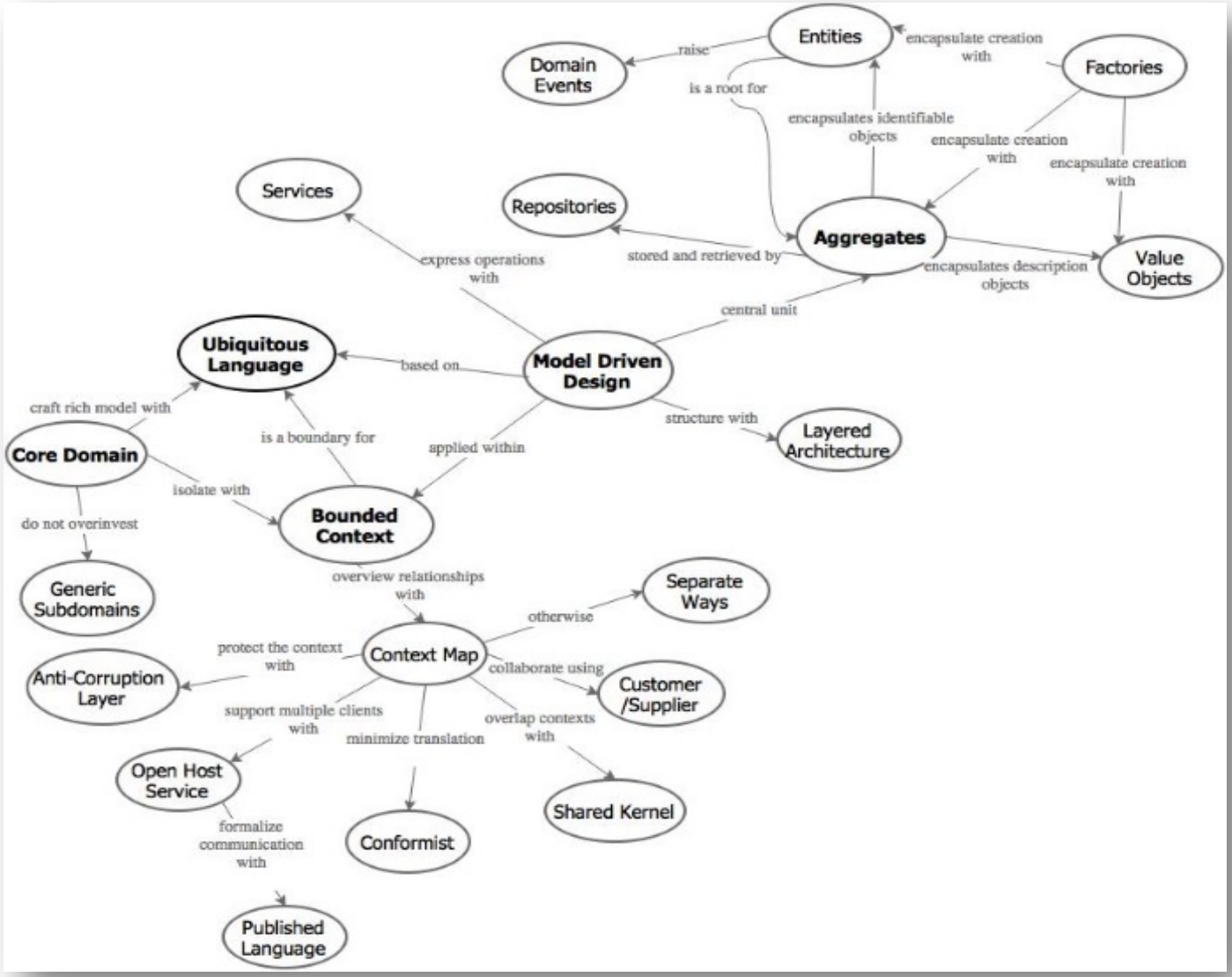
commands to retrieve and manipulate data in database

get, insert, delete, modify

"query language"

AND NOW FOR SOMETHING COMPLETELY DIFFERENT

DDD


Entities
raise
Domain Events
encapsulate creation with
Factories
is a root for
encapsulates identifiable objects
encapsulate creation with
encapsulate creation with
Services
Repositories
Aggregates
Value Objects
express operations with
stored and retrieved by
encapsulates description objects
central unit
Ubiquitous Language
based on
Model Driven Design
craft rich model with
structure with
Layered Architecture
Core Domain
is a boundary for
applied within
isolate with
Bounded Context
do not overinvest
Generic Subdomains
overview relationships with
Separate Ways
otherwise
protect the context with
Context Map
collaborate using
Anti-Corruption Layer
Customer /Supplier
support multiple clients with
minimize translation
overlap contexts with
Open Host Service
Shared Kernel
formalize communication with
Conformist
Published Language

DDD Overview

- DDD stays for Domain Driven Design
- Coined by Eric Evans
- Initially described in “Domain-Driven Design: Tackling Complexity in the Heart of Software” book

DDD: The Definition

DDD is an approach to software development for complex needs by connecting the implementation to an evolving model. The premise of domain-driven design is the following:

- placing the project's primary focus on the core domain and domain logic
- basing complex designs on a model of the domain
- initiating a creative collaboration between technical and domain experts to iteratively refine a conceptual model that addresses particular domain problems

Why should we do DDD?

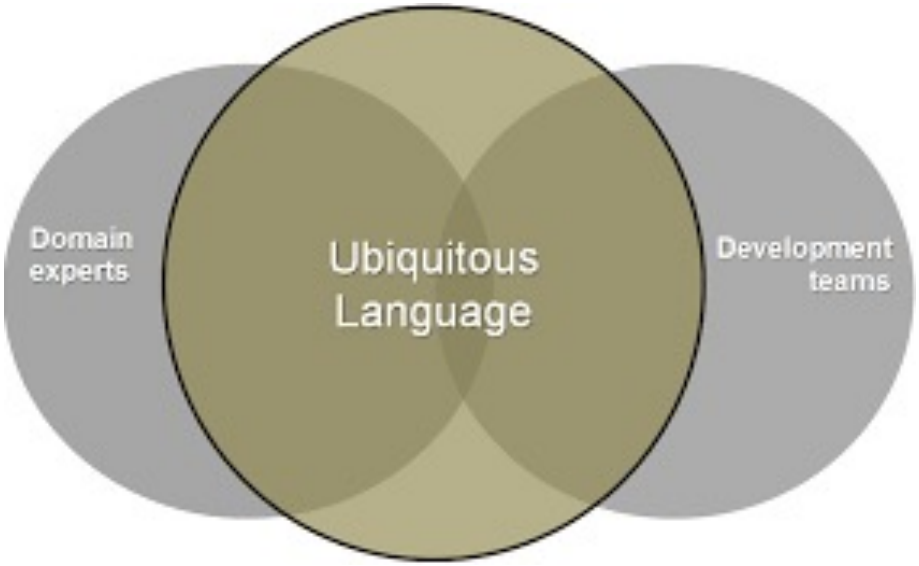
- DDD puts domain experts and developers on the same field, producing software that solves business needs.
- Developers can help business understand their needs better.

Why should we do DDD? (continuation)

- No translations between the domain experts, the software developers, and the software.
- The design is the code, and the code is the design.
- DDD provides software development techniques that address both strategic and tactical design.
  - Strategic design identifies parts of the software which require more development efforts and who must be involved.
  - Tactical design helps us build one particular model which can face complicated business rules and further software evolution.

Ubiquitous Language – what is this?

- Ubiquitous means “pervasive”, “found everywhere”
- Ubiquitous Language - a common, rigorous language between developers and users



Ubiquitous Language – what's this?

- The Language should be based on the Domain Model that a team is building
- The Language should evolve together with the understanding of the domain
- There is one Ubiquitous Language per Bounded Context. Applying a single Ubiquitous Language to an entire enterprise leads to failure.

UL – Online Auction System

Wrong way:

User: When a bidder revokes his bid, we need to recalculate the highest auction bid.

Developer: Right. First, we'll delete the row with revoked bid_id from the bids table. Then in a stored procedure we'll select the bid row with max value and set its id as the highest_bid_id for the corresponding auction record.

User: Delete the row? Can we keep the bid for the history record?

Developer: We might not delete the row, instead we can set its is_active field to false.

User: Hmm.. Ok, anyway, let's try.

UL – Online Auction System

Correct way:

User: When a bidder revokes his bid, we need to recalculate the highest auction bid.

Developer: Right. We will re-apply Highest Bid Calculation Strategy for the Auction. This will calculate the highest from the remaining bids. The Auction will be updated with that new bid.

User: Can we keep the revoked bid for the history record?

Developer: Sure, we'll keep it. We won't remove the bid, it will be marked as revoked and won't be considered in calculations.

User: Great, thanks.

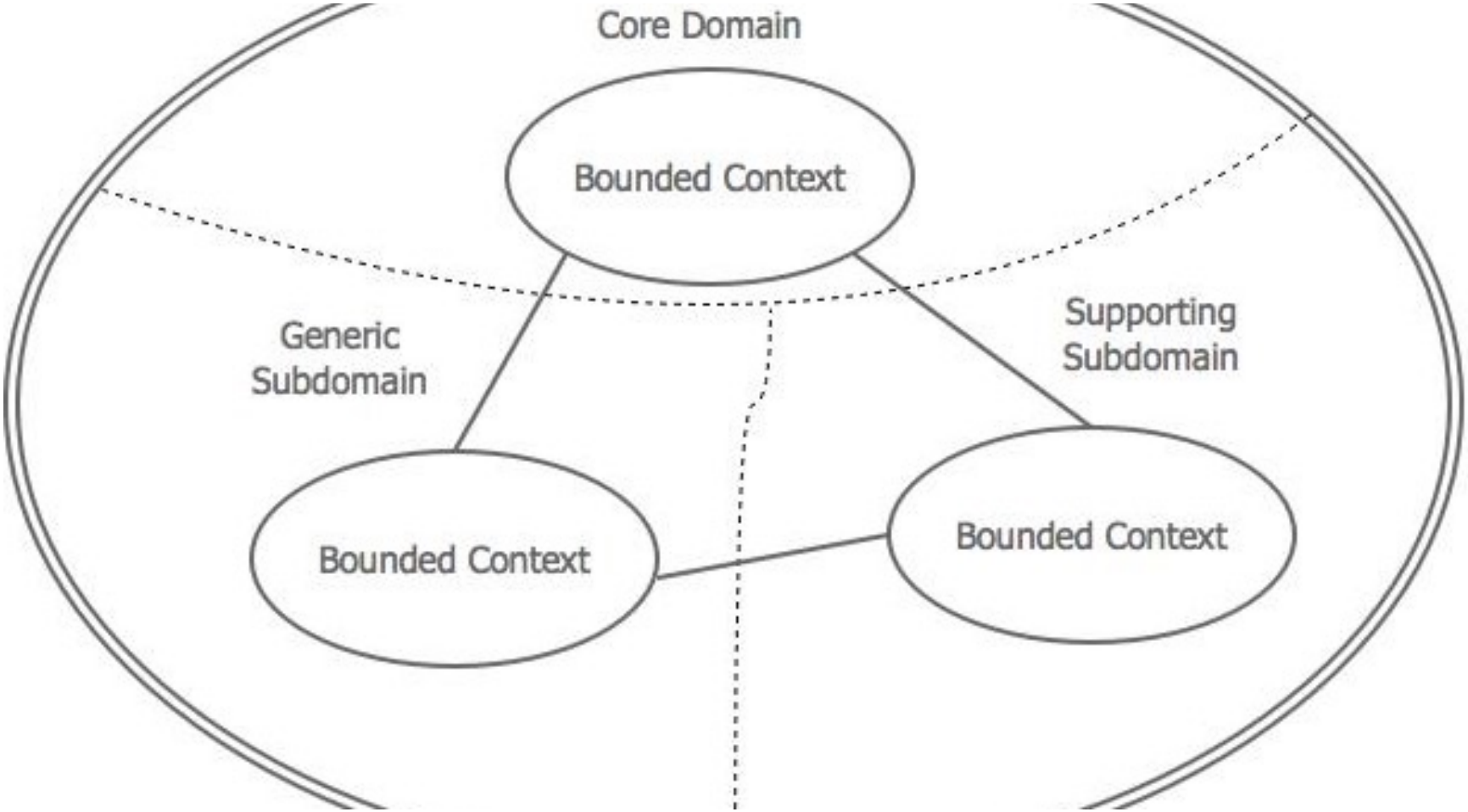
Creating The Language

- Draw pictures of the physical and conceptual domain and label them with names and actions.
- Create a glossary of terms with simple definitions
- Ask the rest of the team for feedback. Continuously improve the Language.

DDD Tools: Strategic Desing

- Strategic Design is a set of principles for maintaining model integrity, distillation of the Domain Model and working with multiple models.
- Strategic Design Patterns:
  - Bounded Contexts – a central pattern in Domain-Driven Design. DDD deals with large models by dividing them into different Bounded Contexts and being explicit about their interrelationships.
  - Context Maps – map of Bounded Contexts and relationships between them

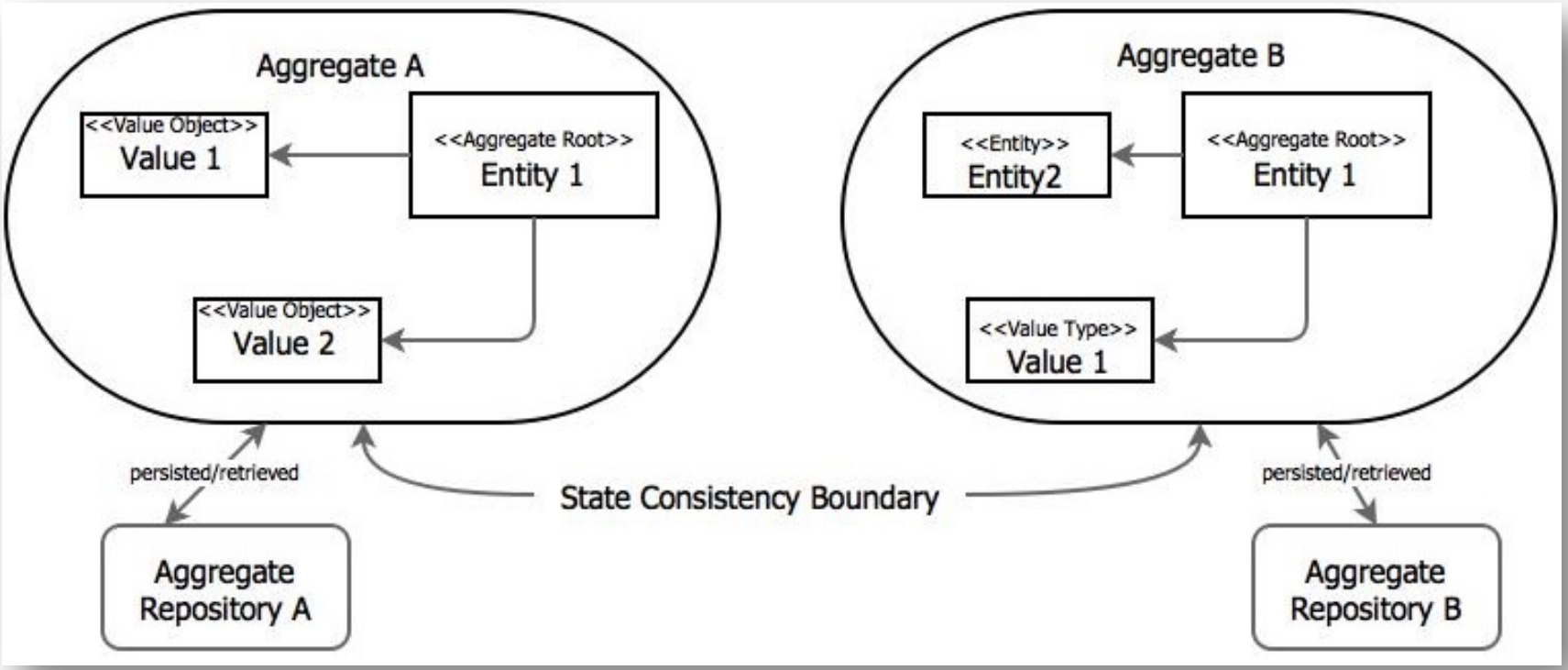
Overview: Domains/Subdomains and Bounded Contexts



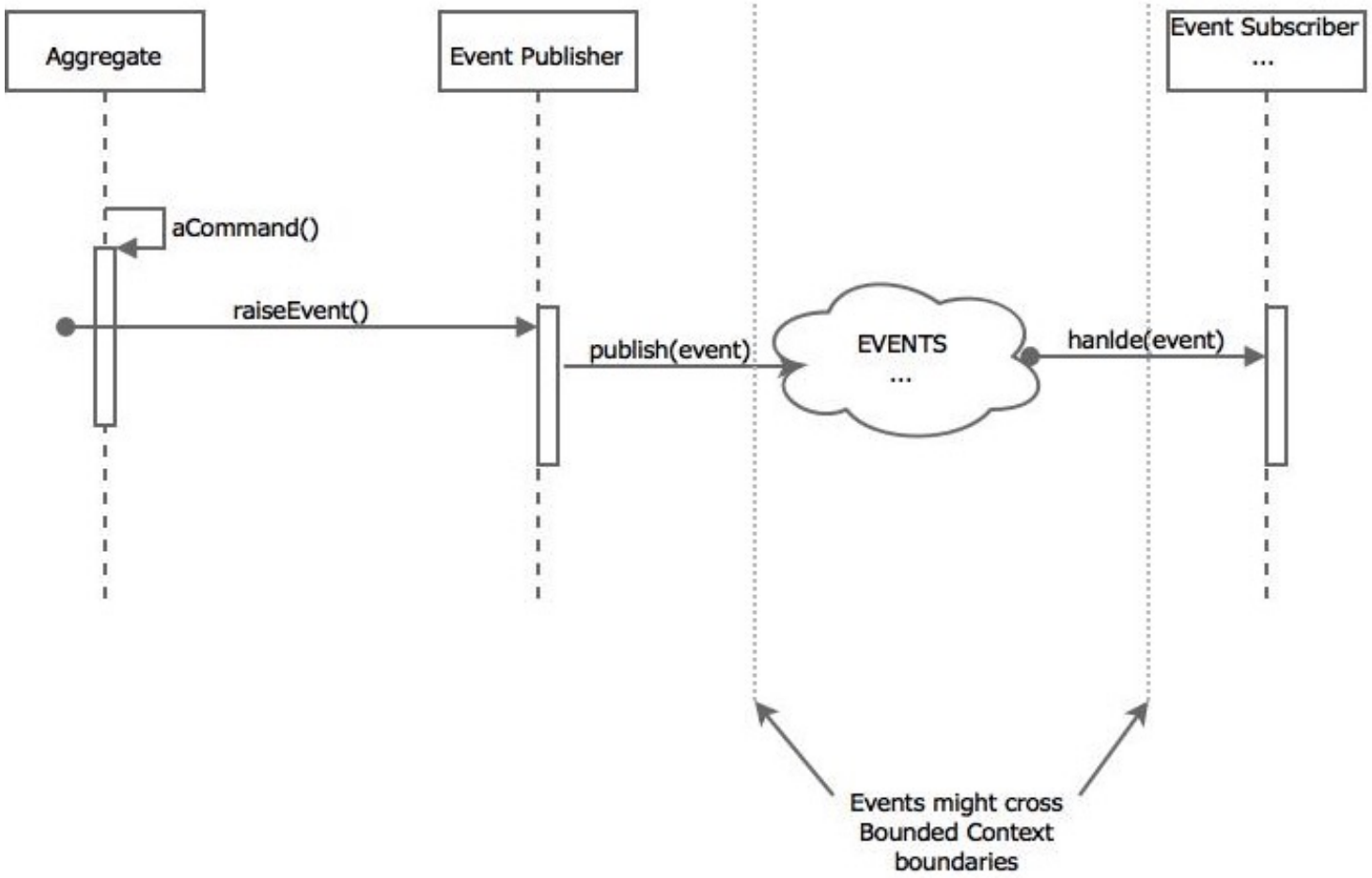
DDD Tools: Tactical Design

- Tactical Design – a set of principles/patterns used when modelling within one Bounded Context. Tactical design is based on OOP and OOD principles.
- Tactical Design Patterns:
  - Aggregate - central tactical pattern.
    - Has: an Aggregate Root, which is an Entity
    - Composed from: Entities, Value Objects
    - Persisted by: Repositories
    - Can generate: Domain Events
    - Can be created by: Factories
    - Operated by: Services
  - Services - Application/Domain/Infrastructure
  - Modules

Overview: Aggregates



Overview: Publishing Events, Services



DDD Antipattern: Anemic Domain Model

- Term coined by Martin Fowler
- Anemic Domain Models (ADM) are models whose domain objects do not express any behavior. Such models cause memory loss (anemia).
- ADM symptoms:
  - Objects have only getters and setters
  - Most (all) of the business logic is implemented in Service/Managers objects.
- Is an anti-pattern for systems with complex business logic
- Can be used in CRUD-only applications

ADM spreading factors

- Code followers. Following code samples with bad design whose focus is on something else
- Infrastructure tools (code generators, orm tools)

ADM Example

```
Client client = clientDao.readClient(clientId);
if (client == null) {
    client = new Client();
    client.setClientId(clientId);
}
if (clientFirstName != null) {
    client.setClientFirstName(clientFirstName);
}
if (clientLastName != null) {
    client.setClientLastName(clientLastName);
}
if (streetAddress != null) {
    client.setStreetAddress(streetAddress);
}
```

ADM: Observations

- Domain experts can’t help here because the code is understandable to developers only.
- There is no explicit intention revealed by the saveClient() interface. Implicit design causes intention memory-loss.
- The implementation of saveClient() adds hidden complexity.
- The Client “domain object” is just a data holder.

Moving from ADM towards DDD

```
public interface Client {

    public void changeName(String firstName, String lastName);

    public void relocateTo(Address address);

    public void changePhoneNumber(Telephone telephone);

    public void emailAddress(EmailAddress emailAddress);

}


@Transactional

public void changeClientPhoneNumber(

    String clientId,

    Telephone telephone) {


    Client client = clientRepository.getById(clientId);
```

Wrap-up

- DDD is an approach for software development, whose primary focus is on Domain
- DDD implies close cooperation between Developers and Domain Experts
- DDD is heavily based on Ubiquitous Language
- DDD implies Strategic Design, Bounded Context being the central pattern of DDD
- DDD comes with a set of Tactical Tools, to implement a domain within a Bounded Context
- Anemic Domain Model is an anti-pattern, very frequently used in wrong places

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Thank you for your attention!

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