04. ER Modeling

[PM Jat, DAIICT, Gandhinagar]

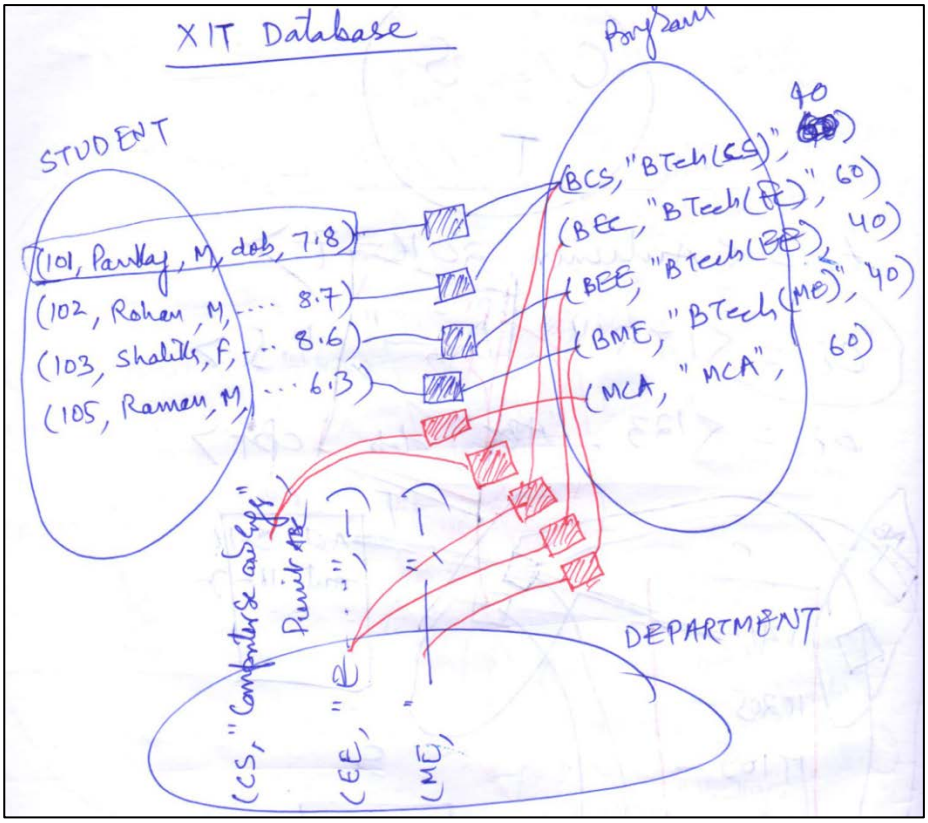
Contents

Entity-Relationship Model

Entity-Relationship is a popular modeling technique at Conceptual Level. Since it is not implementation model, it does not define database manipulation operations.

ER models are depicted using ER Diagrams (ERD).

In ER model, database is seen as a group of Entities and interactions between these entities. ER model calls interactions as relationships. ER Diagrams are primarily used as first hand sketch for database design – aims to capture required data-items with their semantics.



Recall that data model typically captures database schema, and ERD also depicts conceptual schema of the database.

Diagram above shows depiction of XIT database instance using ER Model. The database essentially contains following 5 sets S, P, D, SP and PD. Here S, P, and D are entity sets [of types of Student, Program, and Department respectively], whereas SP and PD are "relationship instance" sets.

ERD for XIT is to contain schema information for said elements of the database.

ER model provide set of primitives that can be used to depict schema; that is ER Diagram. An ER Diagram typically uses following three concepts -

- Entity Types – contains their name and attributes, and key attribute.
- Relationship Types between entities
- Cardinality Constraints and Participation Constraints on relationships between entities

Entity Set

- In ER model first term we introduce is Entity Set. It is a set of entities belonging to a particular "entity type", for example, below is set of student entities. Each element in the set is "entity" or entity instance.

{ID:200701001,Name:Charu,Batch:2007, CPI:6.12},

{ID:200711002,Name:Amit Khanna,Batch:2007,CPI:7.12},

{ID:200711003,Name:Kamla Kiran,Batch:2007,CPI:7.50},

{ID:200711004,Name:Raj Kumar,Batch:2007,CPI:4.00},

{ID:200711005,Name:Raj Tiwari,Batch:2007,CPI:5.56},

{ID:200811001,Name:Rama Kant,Batch:2008,CPI:8.12},

{ID:200811002,Name:Akshya,Batch:2008,CPI:9.22},

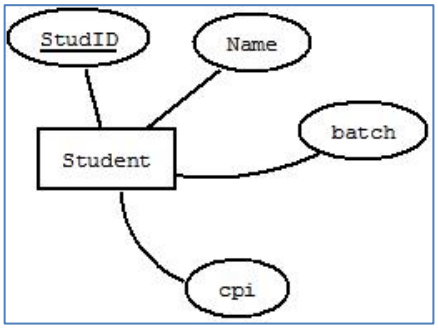
{ID:200811003,Name:Unnati Gupta,Batch:2008,CPI:5.52}

Entity Type

- Entity Type is most important thing in ER model.
- Discovering entity types is often the first thing done in ER Model; it is something that is visible and has independent existence in given database scenario. [A good check for Independent existence - if the thing has "key attribute" to identify itself in set of entities of this type.]
- An Entity Type describes schema for a set of entities.
- In ERD, we describe entity types.

Describing Entity Type in ERD

- Here is notation for describing an entity type.
- A rectangle for Entity Type*, its name is mentioned within it.
- Attributes in ellipse form with their names
- Key attribute is underlined. Value of key attribute is unique, and distinguishes it in its set.



*Note: Notations that are used here for describing ER Diagrams are Chen's notation, were originally suggested by Dr Peter Chen in '76.

Attribute Types:

- Atomic – does not have more than one value in an attribute.
- Key Attributes: are used to identify an entity in its set.
- Composite
- Multi-value
- Stored and Derived attributes

Multi-value attribute

Entity set with entities having multi-value attributes. Student entities below have email as multi-value attribute.

{ID:200701001, Name:Charu, Batch:2007, email:{charu@gmail.com, charu_x@abc.in},CPI:6.8},

{ID:200711002, Name:Amit Khanna, Batch:2007, email:{amil@yahoo.com}, CPI:7.12},

{ID:200711003,Name:Kamla Kiran,Batch:2007, email:{},CPI:7.50},

...

Composite attributes

Composite attributes are composition of more than one value, for example Address composed of Street, City, and PIN.

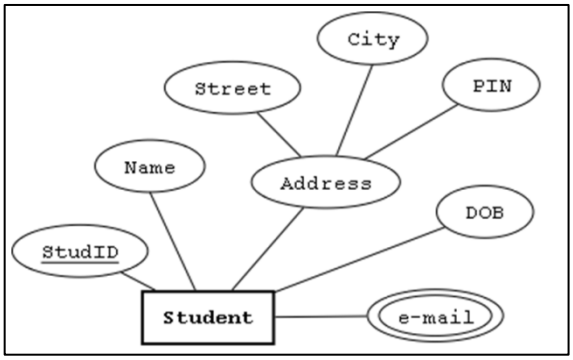
{ID:200701001, Name:{Fname:Charu,Minit:K, Lname:Chawla}, Batch:2007, CPI:6.8},

{ID:200711002, Name:{Fname:Amit,Minit:C, Lname:Patel}, Batch:2007, CPI:7.12},

{ID:200711003, Name:{Fname:Kamla,Minit:S, Lname:Kiran}, Batch:2007, CPI:7.50},

...

Diagram side by shows depiction of multi-value and composite attributes. Address is composite attribute while email is multi-value attribute.



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Observe semantics captured in following two representation of same entity. In first Name is composite attribute, where second is three different attributes for name.

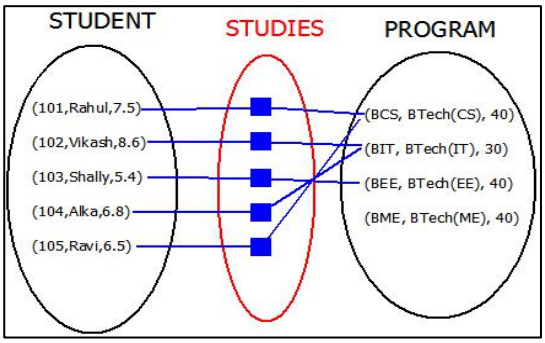
{ID:200701001, Name:{Fname:Charu,Minit:K, Lname:Chawla}, Batch:2007, CPI:6.8}

{ID:200701001, Fname:Charu, Minit:K, Lname:Chawla, Batch:2007, CPI:6.8}

Relationships

Relationship instance set

Diagram here shows that student entities are associated with program entities.



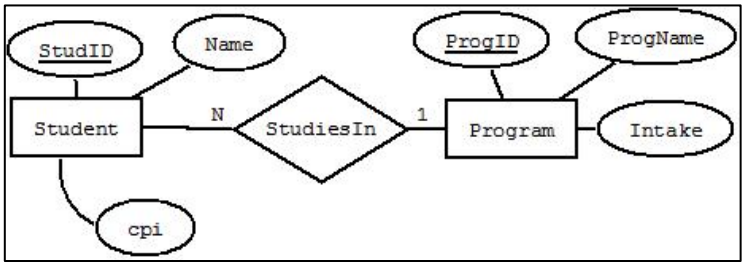
This forms a set of instances of associations between instances of entity types is known as "Relationship instance set" in ER modeling.

A relationship instance is identified (in its set) jointly by key attributes values of "participating entities".

This also describes a relationship type between these two entity types. Relationship type has name, for example "STUDIES" in this case.

Relationship [Type] in ER Diagram

Relationships types are shown as diamond in ER Diagram. The diagram below captures the fact that a student studies in a program.

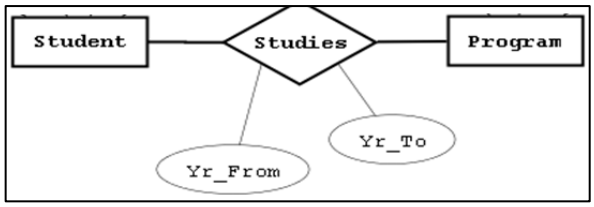


It can be read as following- STUDENT and PROGRAM entity types are related by "STUDIES-IN" relationship type.

The label within the diamond gives name to the relationship.

It is a binary relationship. Binary relationship associates two entity types. Entities are said to be participating in to the relationship.

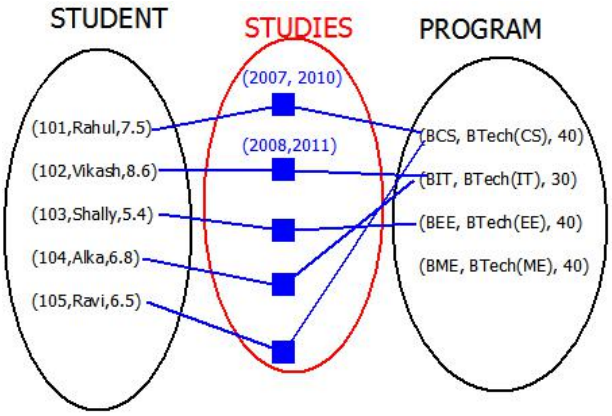
Relationship can have attributes too. In the example here, suppose we want to say a student studies in a program from this year to that year. Can be depicted as following



In our previous example, suppose we also want to have study duration of a student in a program, then

Let us say, we have attributes year_from, and year_to.

Diagram below shows relationship instance for the same



Cardinality Constraints in ERD

One of main constraint specified in ERD is Cardinality Constraint. It specifies number of instance an entity from one side can associate with entities on other side. For instance a student (entity from one side) can be associated with at-most (and at-least) one department (entity on other side).

There are three types of cardinality constraints wee have -

- One to One (1:1)
- One to Many (1:N) [flipped is Many to One (N:1)]
- Many to Many (M:N)

In some texts, this is also referred as Cardinality Ratio (for example Elmasri/Navathe); but this is not really ratio in precise terms. Probably people call it ratio as it is expressed in ratio form (1:N)!

We will use the term "Cardinality Constraints"

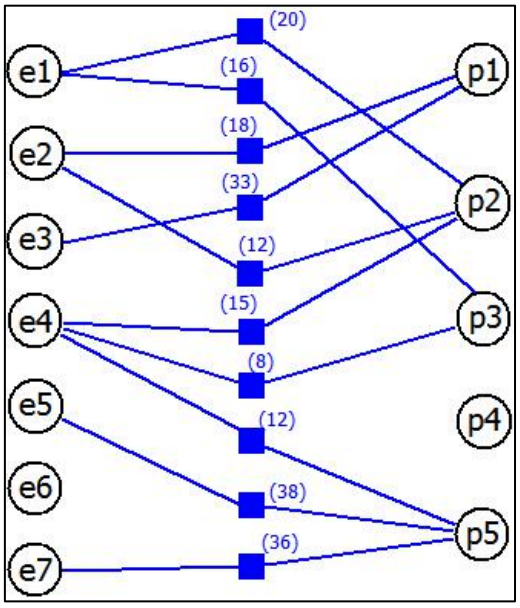
You can use following decision flow to figure out cardinality constraint for a relationship.

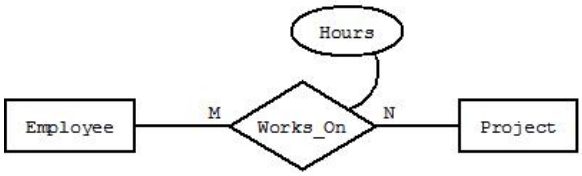
Take an entity from one side (side1), and see how many entities, it can be associated on other side (side2)
    If answer is 1
        see how many entities on side1, an entity from side2 can be associated with
        If answer is 1
            It is 1:1
        else if answer is more than 1
            It is 1:N
        else if answer is more than 1
        see how many entities on side1, an entity from side2 can be associated with
        If answer is 1
            It is 1:N (actually N:1 but same as 1:N)
        else if answer is more than 1
            It is M:N

Examples:

- A student gets allocated only one room, and one room can accommodate only one student (1:1).
- An employee works for only one department, where as a department can have any number of employee (1:N).
- A product category can have many products but one product will have only one category (1:N).
- A product category can have many products and one product can belong to many categories (M:N).
- A bill has many items, and an item can occur in many bills.
- A book is published by only one publisher but a publisher can have many books(1:N)

- A book can have many authors, and an author can author many books.
- An employee can work on any number of Projects, and a Project can have any number of employees working on it (M:N)
    - When employee works on a project, we also store for how many hours the employee works on a project
    - Diagram side by and shows instances of employees working on projects.
    - Below is schema depiction of the relationship





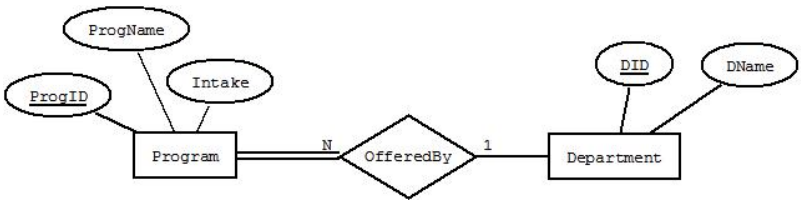
- A property can be owned by many persons, and a person can own many properties.
    - When a person owns a property, we require an additional attribute share_percentage; that what percentage of share the person has for the property.
- Student has one of Professor as Mentor (?:?)
- Course uses Text Book(s), and one text book could be used in multiple courses (?:?)
- A city is in a Country, and Each Country has one of its city as its capital (?:?)

Participation Constraints

Participation constraint specifies whether participation of an entity in a relationship is mandatory or not. Mandatory means an entity cannot exists in its set without participating in the relationship. That is it is necessary that an entity needs to be associated with some entity on the other side. Such a participation constraint is referred as "Total". If it is not mandatory (or total) then it is "optional".

For example, a program entity (XIT database) necessarily needs to be associated with some Department. Then Program entity has mandatory (or total) participation in **Offered-By** relationship. (say we have this between program and department). However it is not necessary that a department offers a program. Therefore participating this entity in **offered-by** is not mandatory.

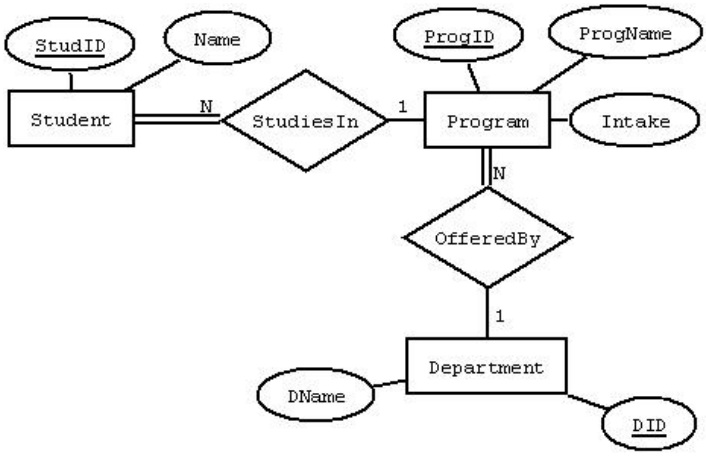
Mandatory participations are shown by double lines while optional participations are shown by single in ERD. Below is depiction of Offer-By relationship.



Examples

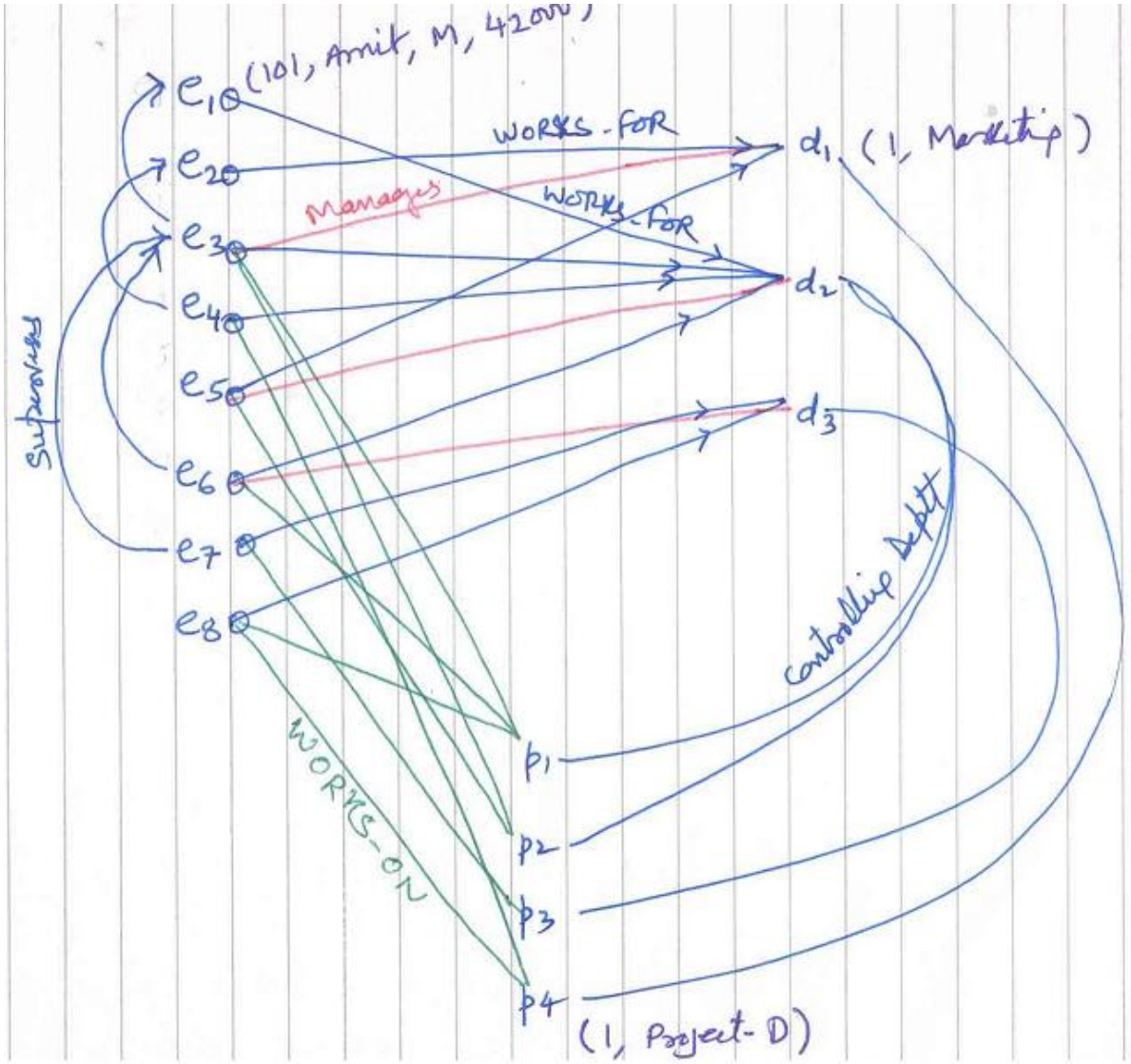
- A student entity may not exist without getting associated with a Program (or in other words without participating in studies-in relationship. However a program may exist.
- An employee may not exist without associated with a department as an employee, however a department may exists.
- An employee may exist without becoming manager of some department
- An employee may exist without working on a project and project having no employee working at all.

Here is complete ERD for XIT schema:



See what sense following sketch containing few instances from employee, department, and project having some interactions.

Attempt sketching ERD for the same-

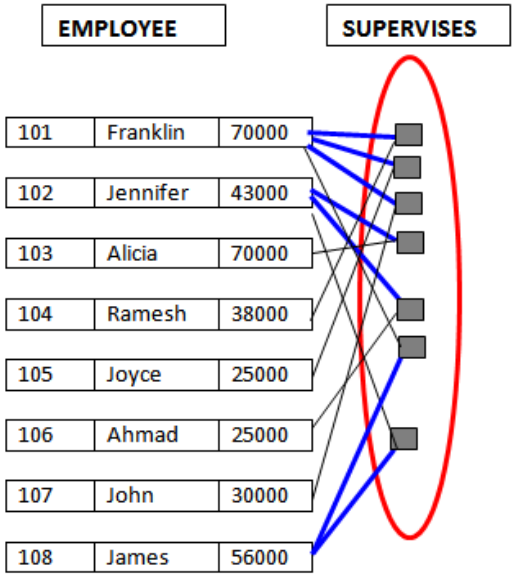


Case Studies#1: TGMC (description given in separate document)

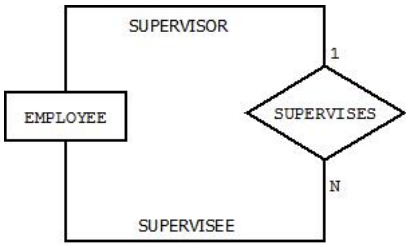
Case Studies#2: Library (description given in separate document

Recursive Relationship

- An entity can be associated with another entity from its own set (same type of entity). For example, as figure below shows, Franklin (101) supervises Ramesh (104); both entities are from set of employee entities, and hence name "recursive relationship".



- Set of little boxes encircled in red forms relationship instances set; let us give name to this relationship type "SUPERVISES"
- Note that there is an issue here – when you have participating entities from different sets (types), roles of entities in relationship is implicit and clear. For example- MANAGES relationship between EMPLOYEE and DEPARTMENT (figure previous page); a "manages" instance where e3 and d1 are interacting (related), expresses the fact that employee e3 manages department d1; and we say that employee e3 plays role of manager while department d1 is managed.
- However this is not the case for recursive relationship. For example, we have instance of e101 and e104 associated in "SUPERVISES" relationship, it is not clear who is supervisor and who is supervisee. Therefore in recursive relationship instance, it is also specified what role an entity plays in the relationship. In this case we say e101 plays role of supervisor and e104 is supervisee. In the diagram blue and thicker line indicates supervisor role while thinner line indicates supervisee role.
- Here is how recursive relationship is depicted in ER Diagram -

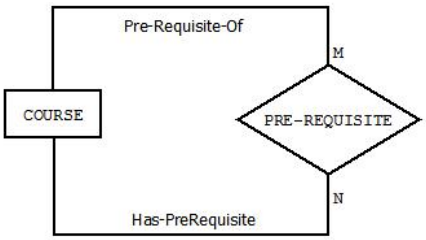


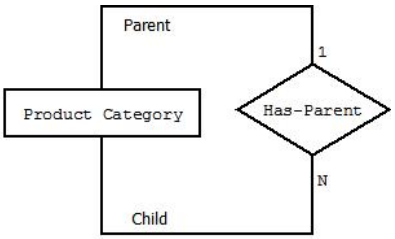
- Note that roles are labeled, and Cardinality and participations constraints are specified for Roles. An employee can play a supervisee role only once, that is can be associate as supervisee with at-most one other employee, where as an employee can act as supervisor with multiple other employees, therefore cardinality is 1:N, supervisee being in many side. For participation both roles are optional; not necessary every employee acts as supervisee, and not necessary an employee supervises any.

More examples of Recursive relationship

(1) A course has another course as pre-requisite (figure below left depicts its ERD). Cardinality: there can be any of courses as pre-requisite of a course, and a course can be pre-requisite of many courses, therefore M:N. Participation: Not necessary every course is pre-requisite of any course, and not necessary every course will have a pre-requisite.

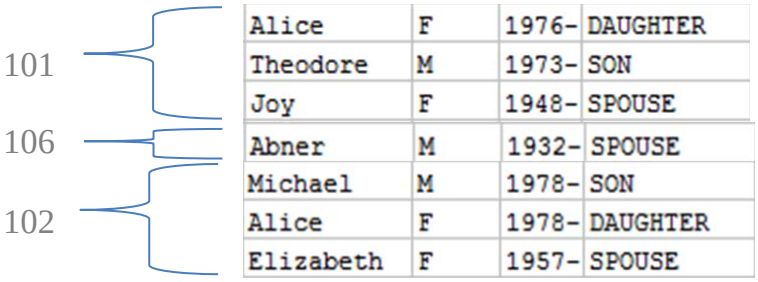
(2) A Product category has another category as parent category. Cardinality: A category can have at most one parent; but a parent can have many multiple children, therefore 1:N. Participation: Not necessary every category will have a parent, and not necessary that a category will have children (figure below right depicts its ERD).





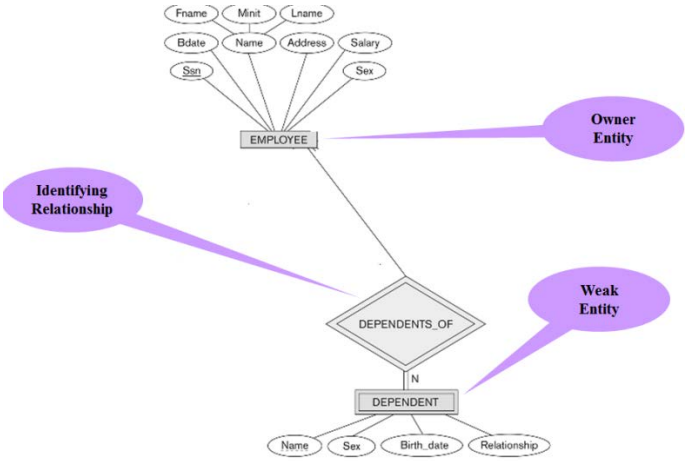
Weak Entity

- When finding key attribute (identifying attribute) for an entity then it is possibly a weak entity. Consider company schema; suppose following details of dependents of employee is to be recorded in database – name, gender, birth_date, relationship with the employee. Let us say below is set of dependents, can you figure out key attribute the set?



- Probably “name” within an employee’s dependents. This is fair assumption.
- When we put dependents from all employees together in a single set, name is no more a key.
- We require adding key of employee to make name distinct in this combined set.
- This is repeating phenomenon in many situations, where an entity has a key but that is key is valid within a subset belonging to one other entity.
- This situation is handled using a notion of *weak entity*; weak entities are always “identified by” some *strong entity*, called as *owner entity*. In the current example of dependents, dependents is a weak entity identified by “Employee”.

- In ER Diagram, weak entity type is modeled as following-



Characteristics of weak entity

- A weak entity is identified by some strong "Owner Entity".
- A weak entity is depicted by double line rectangle; is related with owner entity through "*Identifying Relationship*".
- Identifying relationship is depicted by double line diamond. Cardinality wise, it is always 1:N, weak entity being in many side.
- Participation of weak entity is always total/mandatory.
- Weak entities have *partial key*. Value of partial key is "unique within a single "owner entity". In the example here: dependent name is partial key.

Other examples #1: Player as Weak Entity

- Consider you are organizing a inter college cricket meet; where you have different teams. Each team has different players. While attempting to model this you have a set of team entities, and set of player entities. Let us say we have identified following attributes for Team (name, city, state), and assume that team-names are unique, and hence key for team entity.
- For players, let us say, we have following attributes- name, runs, wickets, sixes, fours). Now what is the key for a player? Player is modeled as "weak entity" identified by Team.

Other examples #2: Room as Weak Entity

- Class Rooms in a University campus? Let us say we have following attributes for room- Room-No, Seating capacity, is_ac, etc. What can be the key for ROOM?
- Room needs to be modeled as Weak Entity identified by Building.
- Remember Room number like CEP-110, KRB-123 captures the same notion; CEP identifies building name while 110 is room no. This kind of representation can be enough for human mind but not enough for computer databases. We need to use building name and room number as separate attributes. In absence of such a separation how do we answer a query like "Give me rooms that having capacity of 200 in CEP building"?

A strong entity in some context may become weak in broadened context (and vice versa)

- In DAIICT scenario course is strong entity having course_no as key. IT214 is unique within DA-IICT. Now consider a database scenario, where courses numbers from different universities are merged for some purpose? Then we need to say IT214 of DA-IICT ==> Course requires an "owner entity" institute, and becomes weak?

In some cases, a weak entity may alternatively be represented as multi-value composite attribute

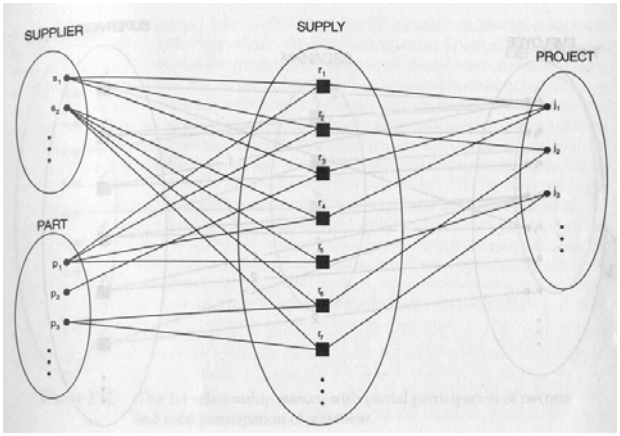
- Can we model dependent as multi-value composite attribute? Possibly yes, and in many such cases this stands out to be an alternative. However, in cases where weak entity participates in some relationship, we may not be alternatively representing it using multi-value composite attribute. For example Player may not be modeled as composite attribute of Team – player is an important entity in sports meet, and interact (have relationships) with other entities like Match.
- Similarly Room may not be modeled as attribute of building – room may be associated with courses or so in a time-tabling problem.

Exercise#: Complete ER Diagram for the company schema.

Caution while creating ER Diagrams

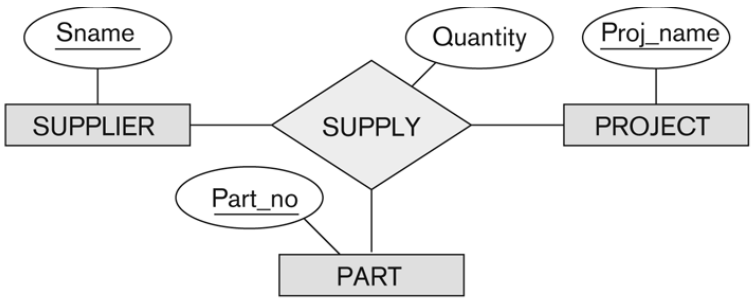
- Attributes like DNO in employee entity, mgrssn in department sound like correct; but really not, these attributes basically captures a relationships; and relationships are represented differently in ER Diagrams.

Ternary Relationship



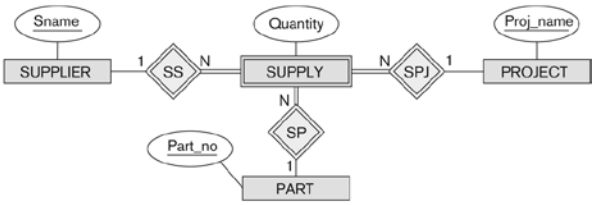
- A relationship in which two entity participate is called as binary relationship. An employee entity e1 and department entity d2 join together and form a binary relationship instance. If a relationship instance has three entities participating into a relationship then it is a ternary.
- Diagram here shows a classical example of ternary. We are three entity sets here- supplier, parts, and projects. This set of associations captures a recordable fact that "a supplier s1 supplies part p1 to project j1", and forms an instance of supply r1; let us name this relationship as SUPPLY.
- It is worth pointing out again that in a ternary relationship instance, we necessarily have three entities from respective sets joining together.

- Diagram below depicts a ternary in ERD -



- Cardinality and Participation constraints for ternary: we will skip this. Constraints (1:1, 1:N, M:N) are for binary. Very few discussions about; and non-standard. Possibly reasons are (1) Most ternary relationship can be represented using binary and "aggregated binary" relationships; (2) Ternary (and more) rarely occur in real situations.
- For participation, we can always extend the same principal for binary to ternary and higher relationship orders.

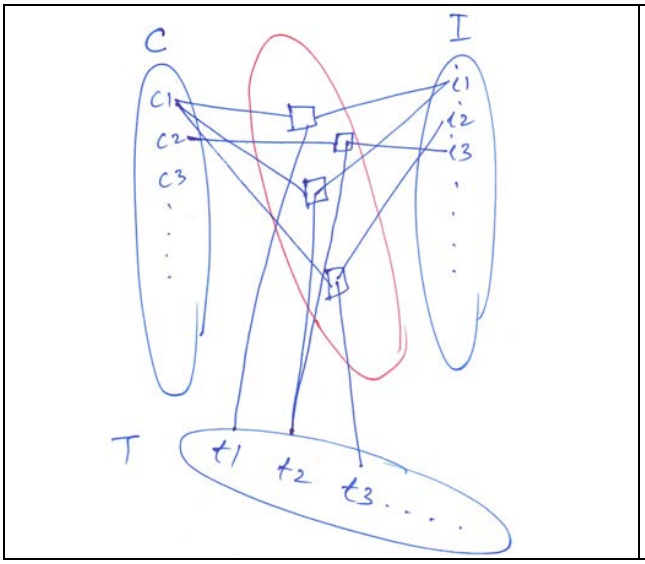
  PS: Ternary relationships can always be representing as weak entity identified jointly by three owner entities (as shown in diagram below)-

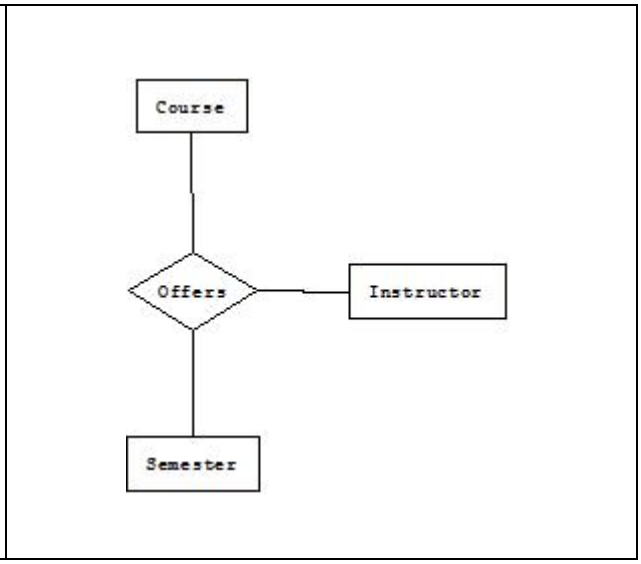


Good news is often we do not need ternary and higher degree relationships.

Other example – "OFFERS: Course-Term-Instructor"

- In DA-Acad scenario: three entities a course (IT214), a term (Autumn'2016), and an instructor (PMJ) join together to form an instance of "course offer" relationship instance. This way a number of such ternary interactions, form set of "course offers". A natural name for this relationship is "Course-Offers", or simply "Offers". Below is an instance set and ERD for "Offers" relationship –





- If a student also joins above offers relationship (to register), will lead to having four entities participating into a relationship, a *Quaternary* relationship? However later on we will establish that this does not correctly capture the situation.

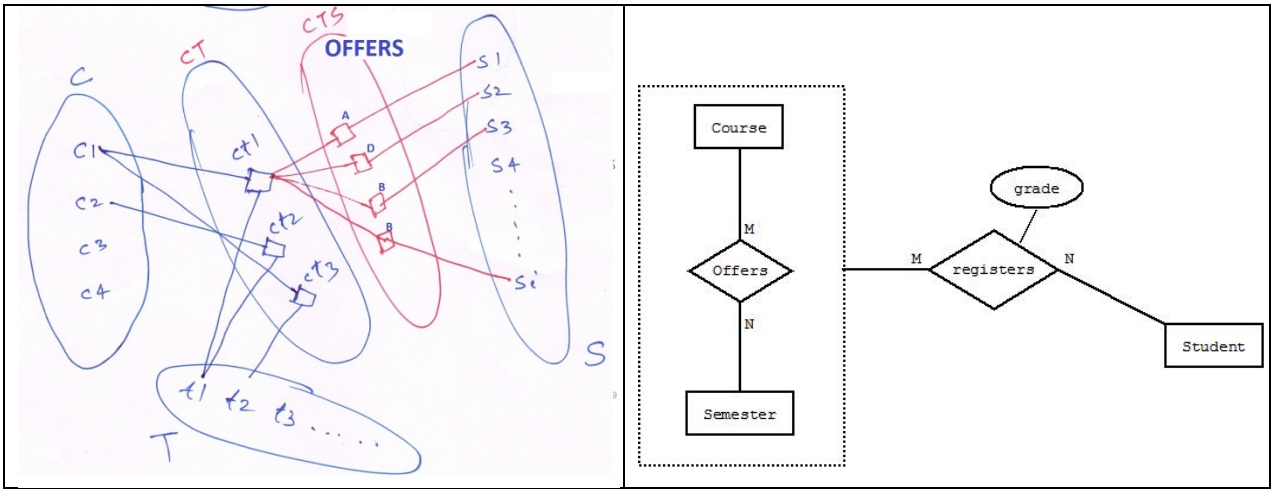
Aggregation

Sometimes, it may look like ternary but may not really be ternary. Let us begin with an example. Consider COURSE, TERM, and STUDENT entities sets in DA_Acad scenario. A registration instance seems like ternary - three entities from respective sets joining together. However you must realize that "course offers" is independent of student registering in it. There may not be any student registered in a course-offering?

So we model "course offers" as binary relationship; and associate instance of offers with a student as yet another binary relationship. This technique is called Aggregation.

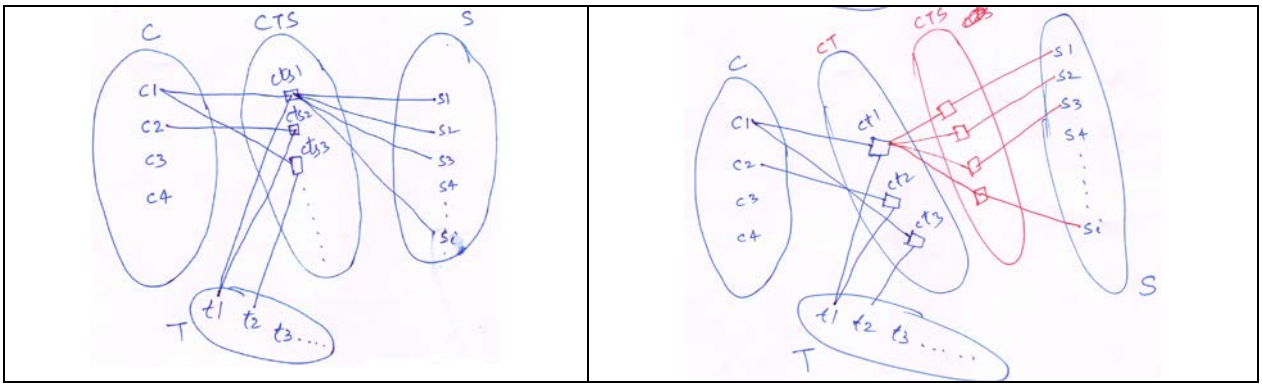
In aggregation, a "relationship instance" is treated like any other entity and allowed to get associated with other entity. For example, we have a binary relationship instance (IT214, Autumn'16); this "relationship instance" can be associated (to represent registration instance) with a student entity 201501123. Figure below capture

Aggregation instances and its ERD depiction are shown below-

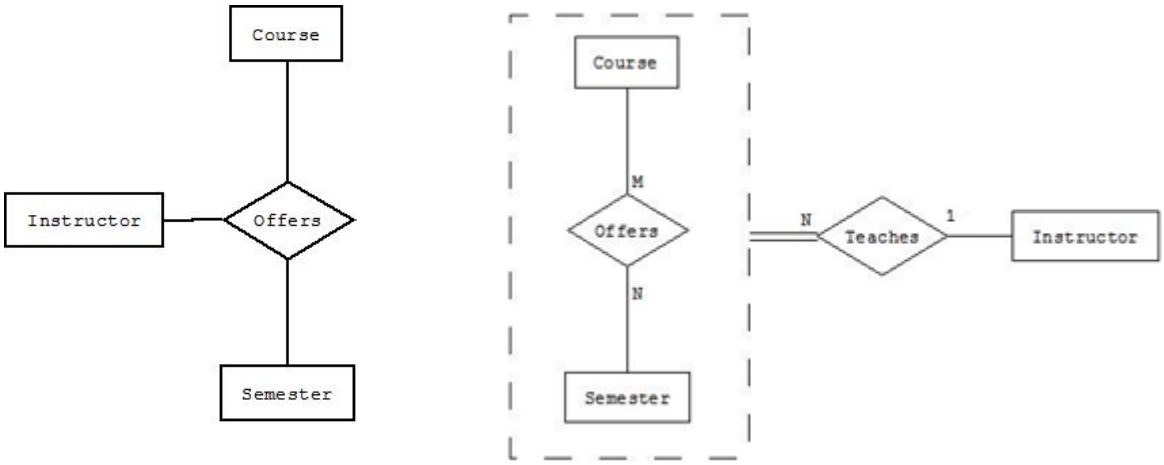


Aggregation and Ternary

Diagram below should capture the differences; “Course-Term-Student” represented both ways.



- In aggregation, association of Course (C) and term (T) is independent of Student (S). Once an instance of CT (c1, t1) is there, it can interact with any student s1 from S, finally forming CTS instance (c1, t1, s1). Assumption in aggregation is that relationship instance (c1, t1) is already there before s1 interacts with it. Whereas in case of ternary, joining of (c1, t1, s1) happens all-together.
- For the purpose of “Registration” where one instance from each set course, term, and student joins to form a registration instance, ternary does not correctly captures the requirement. Aggregation is what correctly represents this situation. First, we have “offering”, as a independent binary instance of C and T, then student s1 joins instance (c1,t1). Ternary does not serve required purpose here; offering of a course is independent of student registering into it. Ternary does not correctly capture CTS situation.
- What about COURSE, TERM, INSTRUCTOR? Do we model it using ternary or aggregation? Diagram below depicts it both ways?



Both are identical here and should be fine in this case, assuming that there is always need to associate an instructor with a Course-Term instance, i.e. course offering. However cardinality of an instructor’s association with a “course offering” can be better represented using aggregation.

Ternary and Aggregation may turn out to be same when participation of third entity is mandatory.

Final Words: Aggregation is always preferred over ternary wherever possible!

- Ternary and higher may not be very popular in OLTP applications but could be quite common in data warehouse/OLAP applications:
- Supply-Part-Project (qty being relationship attribute) should also be drawn from some OLAP application.
- As another example, we have Doctor, Drug, Ailment, a ternary relationship and #no-of-cases being the relationship attribute; useful of some OLAP. It could possibly built from OLTP entities and relationship as follows-
    - Doctor and Patient in binary relationship "consults"– attributes could be consultation fees etc
    - Consults then "aggregately" participates with drugs, and ailments

ER Guidelines:

- Every entity type should be important in its own right within the problem domain
- Must have more than one attributes and "identifying attributes". One attribute entities can be better attached with another entity as an additional attribute.
- A relationship instance should be identifiable by keys of its participating entities; if not then relationship may need to be modeled as entity/weak entity. For example Issues in library scenario; billed in billing scenario.
- IF an entity type has only one instance, THEN it is not modeled as entity, for example DAIICT in DA-Acad; Challenge in TGMS, or so
- Some verbs in requirement description may sound like relationship but actually may not be really relationships, for example
    - Student Fills Enrollment Form. Here neither Enrollment form is entity nor FillsIn is a relationship
    - Team registers in a competition?
- Some relationship may look like ternary or higher degree but in most cases it is not. Explore binary alternatives, aggregation before really making a relationship ternary.

Database Case Studies/Projects

Steps

- Understand Database Requirement and Document them
- Identifying Entities and relationships is an iterative process
    - Note down all entities that comes to your mind.
    - Try finding out sets for each entity type that you have noted
    - Some will get eliminated
    - For relationships, try Identifying possible interactions that are happening between entities, and so

Understand Database Requirement

- Describe database requirements.
- May also have representative list of queries that your database is expected to answer (may not be feasible for real database designs but for student projects you should be able to always do this, and should do it). [refer sample description for Acad-DA and others shared as problem description)

Entity Identification:

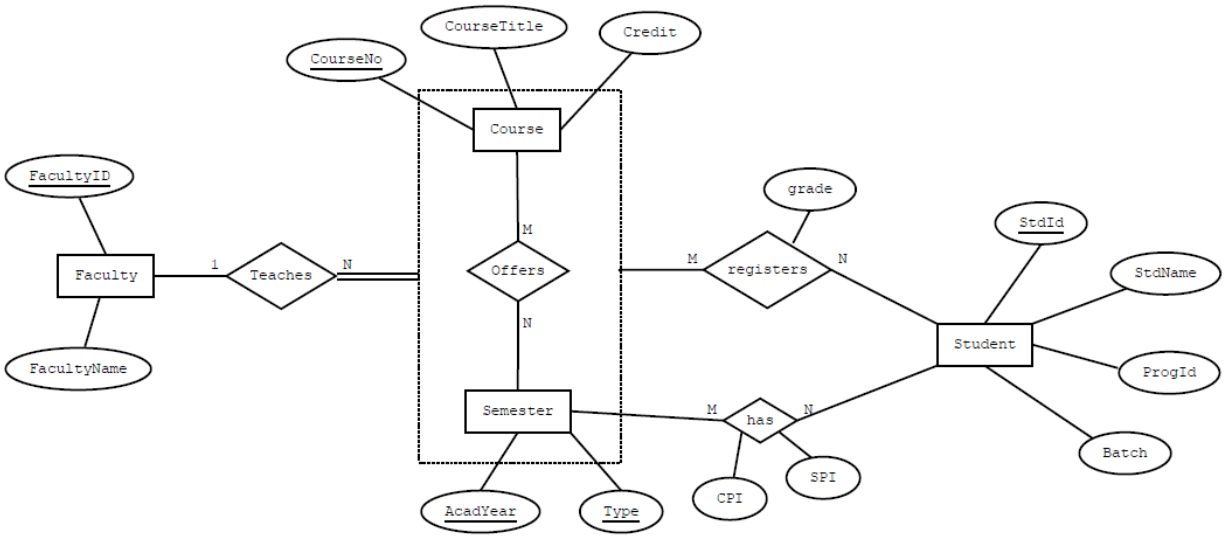
    - Common is Noun Analysis. (We will see other approach). Intuition is Entities are found in NOUNS occurring in database requirement description.
    - A noun that sounds like something "important" in the problem description.
    - Should have a group of "attributes" that are used for describing an entity.
    - Should be able to find out one or more attributes as "Identifying Attributes".
    - Following are typical entity types
        - People - Employees, Students, Customers
        - Places: sites or locations - Cities, Offices, Routes
        - Things: tangible physical objects - Equipment, Products, Buildings
        - Organizations: Teams, Suppliers, Departments
        - Concepts: intangible ideas that track business or other activities - Projects, Accounts, Complaints, Invoice
- Relationships
    - Verbs Analysis. Relationships are potentially found in verbs. Try identifying various interactions entities take place.

An informal strategy of identifying entity and relationships

List down all attributes, and cluster them; possible each cluster will represent an entity, some attributes may actually represent relationships or may belong to relationships. In the examples below red italics attributes either represent relationship or relationship attribute.

- Example #1: Company Database
  - ssn, ename, bdate, *dno_of_employee*, employee_gender, *ssn_of_supervsior*,
  - dno, dname, *ssn_of_department_manager, manager_start_date* (current manager joining date), department_locations (a department has multiple locations)
  - proj_no, proj_name, proj_location, dno_that_controls_project,
  - *HOURS an employee works on a project*; an employee can work on multiple project, and a project can have multiple employees working on it.
  - Dependent details of each employee: dep_name, gender, bdate od dependent, relationship with employee,
  - *ssn_of_employee_of_dependent*

- Example #2: DA-Acad Database
  - AcadYear,
  - Semester,
  - StudentID,
  - Student_Name,
  - Student_Batch,
  - Student_CPI
  - InstructorID,
  - InstructorName,
  - CourseNo,
  - CourseName,
  - Course_Credit,
  - *ID of Instructor that takes a course*,
  - *ID of a students that takes a course*,
  - *Student_Course_Grade*,
  - *Student_Semester_SPI*



- Example #3: MyFacebook
  [Can really become complicated, but probably interesting]
  - User_ID (unique for each user), User_Name, User_Email, User_Join_date, User_City_Name, User_City_Country,
  - *Friend_ID (a user may have zero or more friends), Friend_Since, Friend_Message_IN_Count, Friend_Message_Out_count*,
  - Post_ID, Post_TimeStamp, Post_Text, *Post_Attachemnt_ID (can be multiple),* Post_Attachemnt_Text, Post_Attachemnt_Type (JPEG, MP3, MP4), Post_Attachemnt_Data, *Post_User_ID* (a user can have multiple)
  - *Post_Like_User_ID* (can be multiple user liking a post), *Post_Comment_ID* (can be multiple comments for a post), *Post_Comment_User_ID* (can be multiple users commenting on a post), Post_Comment_Text, Post_Comment_TimeStamp (can be multiple users commenting on), *Post_Comment_Like_UserID* (can be multiple users commenting on),
  - Post_Comment_Reply_ID (can be multiple replies to a comment), Post_Comment_Reply_UserID, Post_Comment_Reply_Addressed_to_UserID, Post_Comment_Reply_Text, Post_Comment_Reply_Time, Post_Comment_Reply_Like_UserID (can be multiple users commenting on)