## Relational Model

- Table = relation.
- Column headers = *attributes*.
- Row = *tuple*

| name | manf |
|---|---|
| WinterBrew | Pete's |
| BudLite | A.B. |
| ... | ... |

`Beers`

- *Relation schema* = name(attributes) + other structure info., e.g., keys, other constraints. Example: `Beers(name, manf)`.
  - ✥ Order of attributes is arbitrary, but in practice we need to assume the order given in the relation schema.
- *Relation instance* is current set of rows for a relation schema.
- *Database schema* = collection of relation schemas.

## Why Relations?

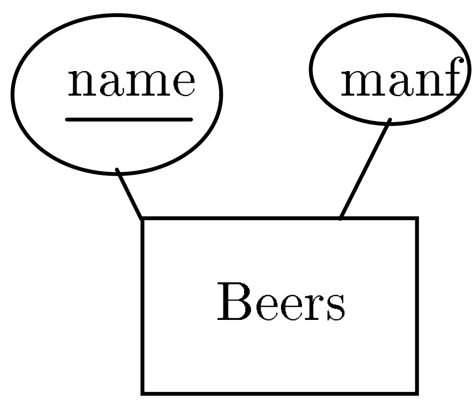
- Very simple model.
- *Often* a good match for the way we think about our data.
- Abstract model that underlies SQL, the most important language in DBMS's today.
    - But SQL uses "bags," while the abstract relational model is set-oriented.

## Relational Design

Simplest approach (not always best): convert each E.S. to a relation and each relationship to a relation.

## Entity Set → Relation

E.S. attributes become relational attributes.



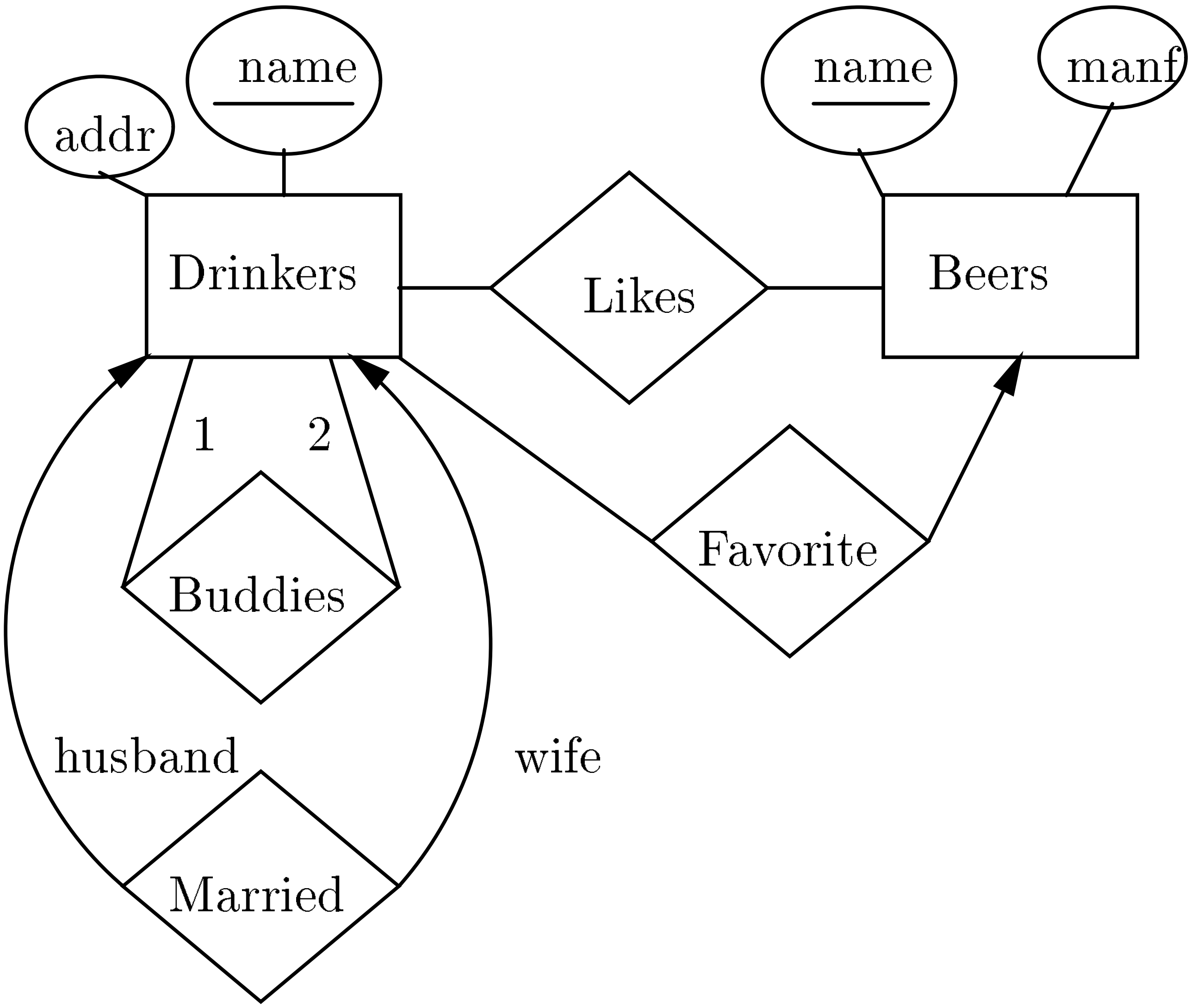

Becomes:

```
Beers(name, manf)
```

## E/R Relationships → Relations

Relation has attribute for *key* attributes of each E.S. that participates in the relationship.

- Add any attributes that belong to the relationship itself.
- Renaming attributes OK.
  - Essential if multiple roles for an E.S.




Likes(drinker, beer)
Favorite(drinker, beer)
Buddies(name1, name2)
Married(husband, wife)

## Combining Relations

Sometimes it makes sense to combine relations.

- Common case: Relation for an E.S. $E$ plus the relation for some many-one relationship from $E$ to another E.S.

## Example

Combine `Drinker(name, addr)` with `Favorite(drinker, beer)` to get `Drinker1(name, addr, favBeer)`.

- Danger in pushing this idea too far: redundancy.
- e.g., combining `Drinker` with `Likes` causes the drinker's address to be repeated viz.:

| name | addr | beer |
|---|---|---|
| Sally | 123 Maple | Bud |
| Sally | 123 Maple | Miller |

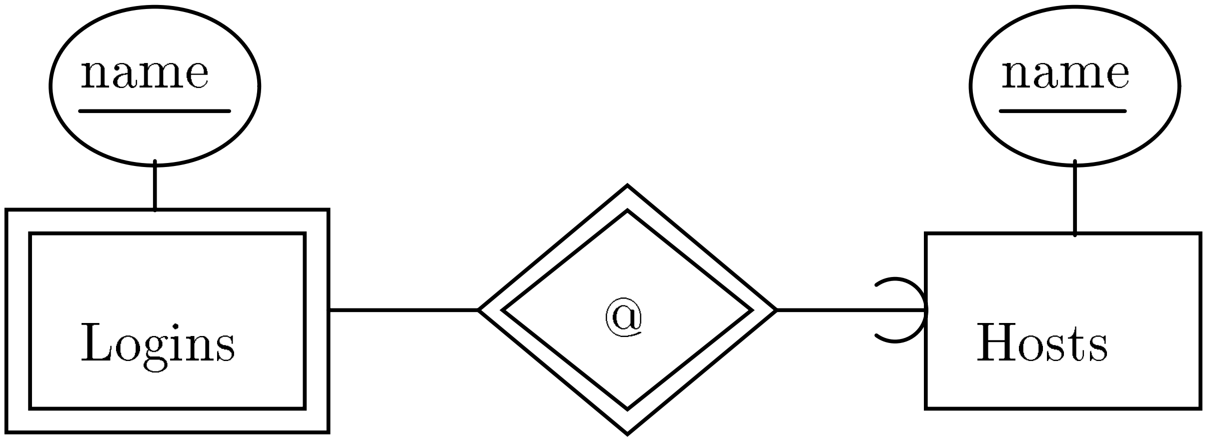
- Notice the difference: `Favorite` is many-one; `Likes` is many-many.

## Weak Entity Sets, Relationships → Relations

- Relation for a weak E.S. must include its full key (i.e., attributes of related entity sets) as well as its own attributes.

- A supporting (double-diamond) relationship yields a relation that is actually redundant and should be deleted from the database schema.

## Example




Hosts(hostName)
Logins(loginName, hostName)
At(loginName, hostName, hostName2)

- In `At`, `hostName` and `hostName2` must be the same host, so delete one of them.
- Then, `Logins` and `At` become the same relation; delete one of them.
- In this case, `Hosts`' schema is a subset of `Logins`' schema. Delete `Hosts`?

## Subclasses → Relations

Three approaches:

1. Object-oriented: each entity is in one class. Create a relation for each class, with all the attributes for that class.

   - Don't forget inherited attributes.

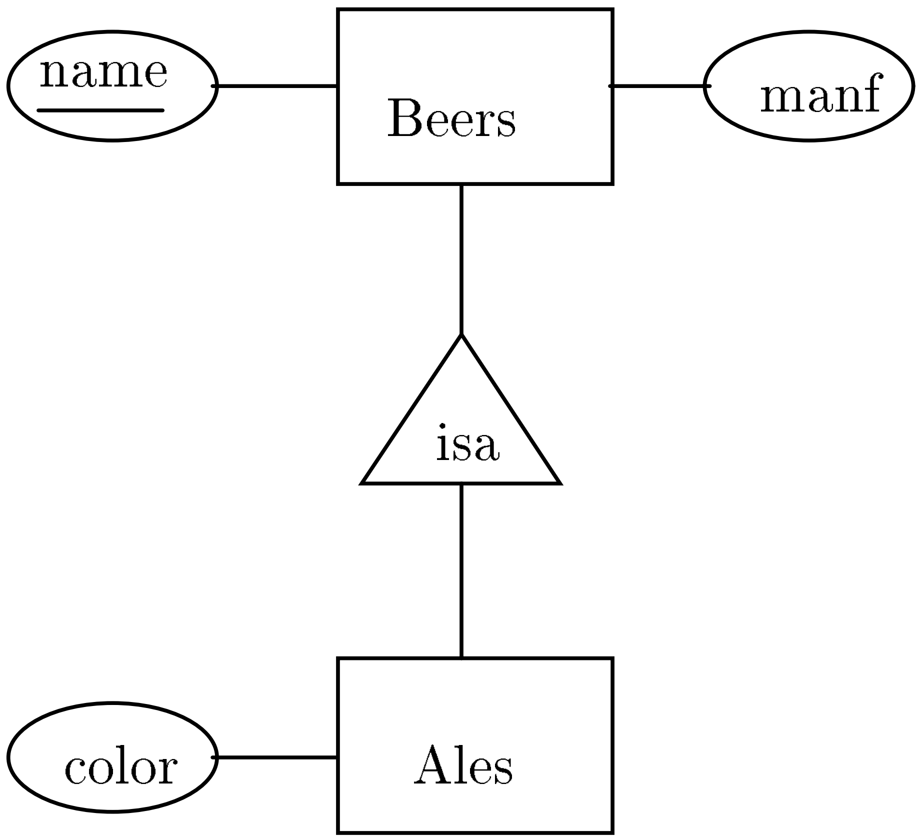
2. E/R style: an entity is in a network of classes related by `isa`. Create one relation for each E.S.

   - An entity is represented in the relation for each subclass to which it belongs.
   - Relation has only the attributes attached to that E.S. + key.

3. Use nulls. Create one relation for the root class or root E.S., with all attributes found anywhere in its network of subclasses.

   - Put `NULL` in attributes not relevant to a given entity.

## Example



## OO-Style

| name | manf |
|---|---|
| Bud | A.B. |

Beers

| name | manf | color |
|---|---|---|
| SummerBrew | Pete's | dark |

Ales

## E/R Style

| name | manf |
|---|---|
| Bud | A.B. |
| SummerBrew | Pete's |

Beers

| name | color |
|---|---|
| SummerBrew | dark |

Ales

## Using Nulls

| name | manf | color |
|---|---|---|
| Bud | A.B. | NULL |
| SummerBrew | Pete's | dark |

Beers

## Functional Dependencies

$X \rightarrow A$ = assertion about a relation $R$ that whenever two tuples agree on all the attributes of $X$, then they must also agree on attribute $A$.

## Example

`Drinkers(name, addr, beersLiked, manf, favoriteBeer)`

| name | addr | beersLiked | manf | favoriteBeer |
|---|---|---|---|---|
| Janeway | Voyager | Bud | A.B. | WickedAle |
| Janeway | Voyager | WickedAle | Pete's | WickedAle |
| Spock | Enterprise | Bud | A.B. | Bud |

- Reasonable FD's to assert:

1. `name` $\rightarrow$ `addr`
2. `name` $\rightarrow$ `favoriteBeer`
3. `beersLiked` $\rightarrow$ `manf`

- Shorthand: combine FD's with common left side by concatenating their right sides.
- Sometimes, several attributes jointly determine another attribute, although neither does by itself. Example:

  `beer bar` $\rightarrow$ `price`

## Keys of Relations

$K$ is a *key* for relation $R$ if:

1. $K \rightarrow$ all attributes of $R$.
2. For **no proper subset** of $K$ is (1) true.

- If $K$ at least satisfies (1), then $K$ is a *superkey*.

## Conventions

- Pick one key; underline key attributes in the relation schema.
- $X$, etc., represent sets of attributes; $A$ etc., represent single attributes.
- No set formers in FD's, e.g., $ABC$ instead of $\{A, B, C\}$.

## Example

`Drinkers(`<u>`name`</u>`, addr, `<u>`beersLiked`</u>`, manf, favoriteBeer)`

- {`name, beersLiked`} FD's all attributes, as seen.
  - Shows {`name, beersLiked`} is a superkey.
- `name` $\rightarrow$ `beersLiked` is false, so `name` not a superkey.
- `beersLiked` $\rightarrow$ `name` also false, so `beersLiked` not a superkey.
- Thus, {`name, beersLiked`} is a key.
- No other keys in this example.
  - Neither `name` nor `beersLiked` is on the right of any observed FD, so they must be part of *any* superkey.
- Important point: "key" in a relation refers to tuples, not the entities they represent. If an entity is represented by several tuples, then entity-key will not be the same as relation-key.

## Who Determines Keys/FD's?

- We could assert a key $K$.
  - Then the only FD's asserted are that $K \rightarrow A$ for every attribute $A$.
  - No surprise: $K$ is then the only key for those FD's, according to the formal definition of "key."
- Or, we could assert some FD's and *deduce* one or more keys by the formal definition.
  - E/R diagram implies FD's by key declarations and many-one relationship declarations.
- Rule of thumb: FD's either come from keyness, many-1 relationship, or from physics.
  - E.g., "no two courses can meet in the same room at the same time" yields `room time` $\rightarrow$ `course`.

## Inferring FD's

And this is important because . . .

- When we talk about improving relational designs, we often need to ask "does this FD hold in this relation?"

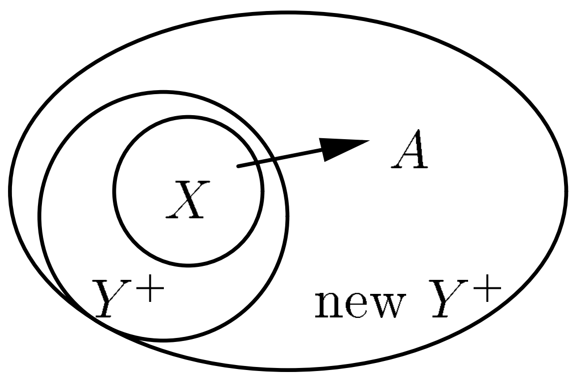
Given FD's $X1 \rightarrow A1$, $X2 \rightarrow A2 \cdots Xn \rightarrow An$, does FD $Y \rightarrow B$ necessarily hold in the same relation?

- Start by assuming two tuples agree in $Y$. Use given FD's to infer other attributes on which they must agree. If $B$ is among them, then yes, else no.

**Algorithm**

Define $Y^+$ = *closure* of $Y$ = set of attributes functionally determined by $Y$:

- Basis: $Y^+ := Y$.
- Induction: If $X \subseteq Y^+$, and $X \rightarrow A$ is a given FD, then add $A$ to $Y^+$.

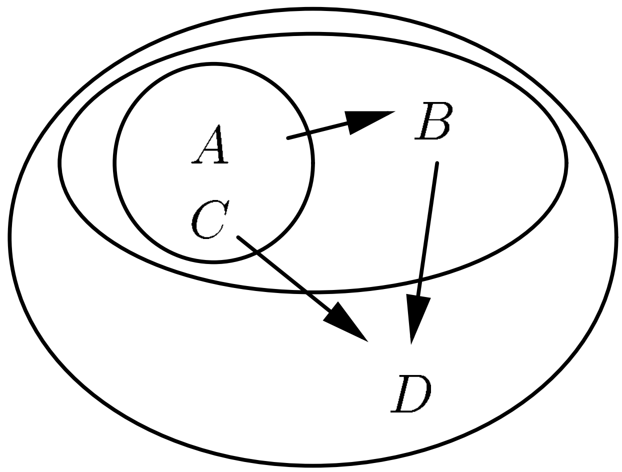



- End when $Y^+$ cannot be changed.

**Example**

$A \to B,\ BC \to D.$

- $A^+ = AB.$
- $C^+ = C.$
- $(AC)^+ = ABCD.$



## Finding All Implied FD's

Motivation: Suppose we have a relation $ABCD$ with some FD's $F$. If we decide to decompose $ABCD$ into $ABC$ and $AD$, what are the FD's for $ABC$, $AD$?

- Example: $F = AB \rightarrow C$, $C \rightarrow D$, $D \rightarrow A$. It looks like just $AB \rightarrow C$ holds in $ABC$, but in fact $C \rightarrow A$ follows from $F$ and applies to relation $ABC$.

- Problem is exponential in worst case.

**Algorithm**

- For each set of attributes $X$ compute $X^+$.
  - But skip $X = \emptyset$, $X =$ all attributes.
  - Add $X \rightarrow A$ for each $A$ in $X^+ - X$.
- Drop $XY \rightarrow A$ if $X \rightarrow A$ holds.
- Finally, project the FD's by selecting only those FD's that involve only the attributes of the projection.
  - Notice that after we project the discovered FD's onto some relation, the eliminated FD's can be inferred *in the projected relation.*

**Example**

In $ABC$ with FD's $A \to B$, $B \to C$, project onto $AC$.

1. $A^+ = ABC$; yields $A \to B$, $A \to C$.
2. $B^+ = BC$; yields $B \to C$.
3. $AB^+ = ABC$; yields $AB \to C$; drop in favor of $A \to C$.
4. $AC^+ = ABC$ yields $AC \to B$; drop in favor of $A \to B$.
5. $C^+ = C$ and $BC^+ = BC$; adds nothing.

- Resulting FD's: $A \to B$, $A \to C$, $B \to C$.
- Projection onto $AC$: $A \to C$.