Background

Relational database systems
Computer networks

Relational Model

- A relation R
  - with attributes $A = \{A_1, A_2, \ldots, A_n\}$
  - defined over n domains $D = \{D_1, D_2, \ldots, D_n\}$
  - with values $\{Dom_1, Dom_2, \ldots, Dom_n\}$

is a finite, time varying set of n-tuples $\langle d_1, d_2, \ldots, d_n \rangle$ such that $d_1 \in Dom_1$, $d_2 \in Dom_2$, …, $d_n \in Dom_n$

Relation Schemes and Instances

- Relation scheme
  - A relation scheme is the definition
  - Notation: $R(A_1, A_2, \ldots, A_n)$ or $R(A_1\colon D_1, A_2\colon D_2, \ldots, A_n\colon D_n)$
  - A relational database scheme is a set of relation schemes

- Relation instance (simply ***relation***)
  - A relation is an instance of a relation scheme
  - A relation **R** over a relation scheme $\{A_1, \ldots, A_n\}$ is a subset of the Cartesian product of the domains of all attributes, i.e.,

$$\mathbf{R} \subseteq Dom_1 \times Dom_2 \times \ldots \times Dom_n$$

Tabular Structure

- Relation scheme is the table heading
- Attributes are table column names
- Each tuple is a row

Relation Schemes

EMP

ENO	ENAME	TITLE	SAL	PNO	RESP	DUR

PROJ

PNO	PNAME	BUDGET

EMP(ENO, ENAME, TITLE, SAL, PNO, RESP, DUR)

PROJ (PNO, PNAME, BUDGET)

- Underlined attributes are the relation key (tuple identifier).

Relation Instances

EMP

ENO	ENAME	TITLE	SAL	PNO	RESP	DUR
E1	J. Doe	Elect. Eng.	40000	P1	Manager	12
E2	M. Smith	Analyst	34000	P1	Analyst	24
E2	M. Smith	Analyst	34000	P2	Analyst	6
E3	A. Lee	Mech. Eng.	27000	P3	Consultant	10
E3	A. Lee	Mech. Eng.	27000	P4	Engineer	48
E4	J. Miller	Programmer	24000	P2	Programmer	18
E5	B. Casey	Syst. Anal.	34000	P2	Manager	24
E6	L. Chu	Elect. Eng.	40000	P4	Manager	48
E7	R. Davis	Mech. Eng.	27000	P3	Engineer	36
E8	J. Jones	Syst. Anal.	34000	P3	Manager	40

Degree = 7
Cardinality = 10

PROJ

PNO	PNAME	BUDGET
P1	Instrumentation	150000
P2	Database Develop.	135000
P3	CAD/CAM	250000
P4	Maintenance	310000

Degree = 3
Cardinality = 4

Keys

- A key of a relation scheme is the minimum non-empty subset of its attributes such that the values of the attributes comprising the key uniquely identify each tuple of the relation.
- The attributes that make up the key are called prime attributes.

- A superset of a key is called a superkey

- Sometimes, there may be more than one possibility for the key.
- One of the candidate keys is chosen as the ***primary key.***

- An attribute that is not part of any candidate key is known as non-prime attribute.

Repetition Anomaly

- The NAME,TITLE, SAL attribute values are repeated for each project that the employee is involved in.
  - Waste of space
  - Complicates updates

EMP

ENO	ENAME	TITLE	SAL	PNO	RESP	DUR
E1	J. Doe	Elect. Eng.	40000	P1	Manager	12
E2	M. Smith	Analyst	34000	P1	Analyst	24
E2	M. Smith	Analyst	34000	P2	Analyst	6
E3	A. Lee	Mech. Eng.	27000	P3	Consultant	10
E3	A. Lee	Mech. Eng.	27000	P4	Engineer	48
E4	J. Miller	Programmer	24000	P2	Programmer	18
E5	B. Casey	Syst. Anal.	34000	P2	Manager	24
E6	L. Chu	Elect. Eng.	40000	P4	Manager	48
E7	R. Davis	Mech. Eng.	27000	P3	Engineer	36
E8	J. Jones	Syst. Anal.	34000	P3	Manager	40

Update Anomaly

- If any repeated attribute (say SAL) is updated, multiple tuples have to be updated to reflect the change.

EMP

ENO	ENAME	TITLE	SAL	PNO	RESP	DUR
E1	J. Doe	Elect. Eng.	40000	P1	Manager	12
E2	M. Smith	Analyst	34000	P1	Analyst	24
E2	M. Smith	Analyst	34000	P2	Analyst	6
E3	A. Lee	Mech. Eng.	27000	P3	Consultant	10
E3	A. Lee	Mech. Eng.	27000	P4	Engineer	48
E4	J. Miller	Programmer	24000	P2	Programmer	18
E5	B. Casey	Syst. Anal.	34000	P2	Manager	24
E6	L. Chu	Elect. Eng.	40000	P4	Manager	48
E7	R. Davis	Mech. Eng.	27000	P3	Engineer	36
E8	J. Jones	Syst. Anal.	34000	P3	Manager	40

Insertion Anomaly

- It may not be possible to store information about a new employee until a project is assigned to it.

EMP

ENO	ENAME	TITLE	SAL	PNO	RESP	DUR
E1	J. Doe	Elect. Eng.	40000	P1	Manager	12
E2	M. Smith	Analyst	34000	P1	Analyst	24
E2	M. Smith	Analyst	34000	P2	Analyst	6
E3	A. Lee	Mech. Eng.	27000	P3	Consultant	10
E3	A. Lee	Mech. Eng.	27000	P4	Engineer	48
E4	J. Miller	Programmer	24000	P2	Programmer	18
E5	B. Casey	Syst. Anal.	34000	P2	Manager	24
E6	L. Chu	Elect. Eng.	40000	P4	Manager	48
E7	R. Davis	Mech. Eng.	27000	P3	Engineer	36
E8	J. Jones	Syst. Anal.	34000	P3	Manager	40

Deletion Anomaly

- If an employee works on only one project, and that project is terminated, it is not possible to delete the project information from the EMP relation.

EMP

ENO	ENAME	TITLE	SAL	PNO	RESP	DUR
E1	J. Doe	Elect. Eng.	40000	P1	Manager	12
E2	M. Smith	Analyst	34000	P1	Analyst	24
E2	M. Smith	Analyst	34000	P2	Analyst	6
E3	A. Lee	Mech. Eng.	27000	P3	Consultant	10
E3	A. Lee	Mech. Eng.	27000	P4	Engineer	48
E4	J. Miller	Programmer	24000	P2	Programmer	18
E5	B. Casey	Syst. Anal.	34000	P2	Manager	24
E6	L. Chu	Elect. Eng.	40000	P4	Manager	48
E7	R. Davis	Mech. Eng.	27000	P3	Engineer	36
E8	J. Jones	Syst. Anal.	34000	P3	Manager	40

What to do?

- Take each relation individually and "improve" it in terms of the desired characteristics.

- Normalization
  - Normalization is a process of concept separation which applies a top-down methodology for producing a scheme by *subsequent refinements and decompositions*.
  - A relation with one or more of the above-mentioned anomalies is split into two or more relations of a higher *normal form*.
  - 1NF, 2NF, 3NF, BCNF
    - Functional dependencies

Functional Dependence

- Given relation R defined over $U = \{A_1, A_2, \ldots, A_n\}$ and $X \subseteq U$, $Y \subseteq U$. If, for all pairs of tuples t_1 and t_2 in any legal instance of relation scheme R,

  $$t_1[X] = t_2[X] \Rightarrow t_1[Y] = t_2[Y],$$

  then the functional dependency $X \rightarrow Y$ holds in R.
- The key of a relation functionally determines the non-key attributes of the same relation.
  - (ENO, PNO) $\rightarrow$ (ENAME, TITLE, SAL, DUR, RESP)
  - PNO $\rightarrow$ (PNAME, BUDGET)
- Other examples in relation EMP
  - ENO $\rightarrow$ (ENAME, TITLE, SAL)
  - TITLE $\rightarrow$ SAL

Normalization Issues

- What criteria should the decomposed schemas follow in order to preserve the semantics of the original schema?
  - Reconstructability: recover the original relation ⇒ no spurious joins
  - Lossless decomposition: no information loss
  - Dependency preservation: the dependencies that hold on the original relation should be enforceable by means of the dependencies defined on the decomposed relations.
- What happens to queries?
  - Processing time may increase due to joins
  - Denormalization

Normal Forms Based on FDs

eliminate composite or multi-valued attributes

↓

First Normal Form (1NF)

eliminate the partial functional dependencies of non-prime attributes to key attributes

↓

Second Normal Form (2NF)

eliminate the transitive functional dependencies of non-prime attributes to key attributes

↓

Third Normal Form (3NF)

Normalized Relations - Example

EMP

ENO	ENAME	TITLE	SAL	PNO	RESP	DUR
E1	J. Doe	Elect. Eng.	40000	P1	Manager	12
E2	M. Smith	Analyst	34000	P1	Analyst	24
E2	M. Smith	Analyst	34000	P2	Analyst	6
E3	A. Lee	Mech. Eng.	27000	P3	Consultant	10
E3	A. Lee	Mech. Eng.	27000	P4	Engineer	48
E4	J. Miller	Programmer	24000	P2	Programmer	18
E5	B. Casey	Syst. Anal.	34000	P2	Manager	24
E6	L. Chu	Elect. Eng.	40000	P4	Manager	48
E7	R. Davis	Mech. Eng.	27000	P3	Engineer	36
E8	J. Jones	Syst. Anal.	34000	P3	Manager	40

1NF

ASG(<u>ENO</u>,<u>PNO</u>,RESP,DUR)
3NF
EMP(<u>ENO</u>, ENAME,TITLE,SALARY)
2NF

EMP(<u>ENO</u>, ENAME,TITLE)
PAY(<u>TITLE</u>,SALARY))
3NF

PROJ

PNO	PNAME	BUDGET
P1	Instrumentation	150000
P2	Database Develop.	135000
P3	CAD/CAM	250000
P4	Maintenance	310000

3NF

Normalized Relations – Example

EMP

ENO	ENAME	TITLE
E1	J. Doe	Elect. Eng
E2	M. Smith	Syst. Anal.
E3	A. Lee	Mech. Eng.
E4	J. Miller	Programmer
E5	B. Casey	Syst. Anal.
E6	L. Chu	Elect. Eng.
E7	R. Davis	Mech. Eng.
E8	J. Jones	Syst. Anal.

ASG

ENO	PNO	RESP	DUR
E1	P1	Manager	12
E2	P1	Analyst	24
E2	P2	Analyst	6
E3	P3	Consultant	10
E3	P4	Engineer	48
E4	P2	Programmer	18
E5	P2	Manager	24
E6	P4	Manager	48
E7	P3	Engineer	36
E8	P3	Manager	40

PROJ

PNO	PNAME	BUDGET
P1	Instrumentation	150000
P2	Database Develop.	135000
P3	CAD/CAM	250000
P4	Maintenance	310000

PAY

TITLE	SAL
Elect. Eng.	40000
Syst. Anal.	34000
Mech. Eng.	27000
Programmer	24000

Relational Data Languages

- Data manipulation (query) languages
  - Relational algebra
    - Specify how to obtain the result using a set of operators
  - Relational calculus
    - Specify the properties that the result should hold
      - Tuple relational calculus (SQL)
      - Domain relational calculus (QBE)
  - They are equivalent in terms of expressive power
  - Whereas the algebra defines a set of operations for the relational model, the calculus provides a higher-level declarative language for specifying relational queries.

Relational Algebra

- Provides a formal foundation for relational model operations.

Form

$$\langle Operator \rangle_{\langle parameters \rangle} \langle Operands \rangle \rightarrow \langle Result \rangle$$

$$\begin{array}{cc} \downarrow & \downarrow \\ \text{Relations} & \text{Relation} \end{array}$$

Relational Algebra Operators

- Fundamental
  - Selection
  - Projection
  - Union
  - Set difference
  - Cartesian product

- Additional
  - Intersection
  - θ-join
  - Natural join
  - Semijoin
  - Division

Selection

- Produces a horizontal subset of the operand relation
- General form

$$\sigma_F(R)=\{t \mid t \in R \text{ and } F(t) \text{ is true}\}$$

where

- R is a relation, t is a tuple variable
- F is a formula consisting of
  - operands that are constants or attributes
  - arithmetic comparison operators

    $<, >, =, \neq, \leq, \geq$
  - logical operators

    $\wedge, \vee, \neg$

Selection Example

EMP

ENO	ENAME	TITLE
E1	J. Doe	Elect. Eng.
E2	M. Smith	Syst. Anal.
E3	A. Lee	Mech. Eng.
E4	J. Miller	Programmer
E5	B. Casey	Syst. Anal.
E6	L. Chu	Elect. Eng.
E7	R. Davis	Mech. Eng.
E8	J. Jones	Syst. Anal.

$\sigma_{\text{TITLE='Elect. Eng.'}}(\text{EMP})$

ENO	ENAME	TITLE
E1	J. Doe	Elect. Eng
E6	L. Chu	Elect. Eng.

Projection

- Produces a vertical subset of a relation
- General form

$$\Pi_{A_1,\ldots,A_n}(R)=\{t[A_1,\ldots, A_n] \mid t \in R\}$$

  where
  - R is a relation, t is a tuple variable
  - $\{A_1,\ldots, A_n\}$ is a subset of the attributes of R over which the projection will be performed

- Note: Commercial systems and SQL allow
  - Projection with duplicate elimination
  - Projection without duplicate elimination

Projection Example

PROJ

PNO	PNAME	BUDGET
P1	Instrumentation	150000
P2	Database Develop.	135000
P3	CAD/CAM	250000
P4	Maintenance	310000

$\Pi_{\text{PNO,BUDGET}}(\text{PROJ})$

PNO	BUDGET
P1	150000
P2	135000
P3	250000
P4	310000

Union

- General form

$$R \cup S = \{t \mid t \in R \text{ or } t \in S\}$$

  where R, S are relations, t is a tuple variable

  - Result contains tuples that are in R or in S (duplicates removed)
  - R, S should be union-compatible

Set Difference

- General form

$$R - S = \{t \mid t \in R \text{ and } t \notin S\}$$

where R and S are relations, t is a tuple variable

- Result contains all tuples that are in R, but not in S.
- $R - S \neq S - R$
- R, S should be union-compatible

Intersection

- General form

$$R \cap S=\{t \mid t \in R \text{ and } t \in S\}$$

where R, S are relations, t is a tuple variable

- Result contains tuples that are in R and in S
- $R \cap S = R - (R - S)$
- R, S should be union-compatible

Cartesian Product

- Given relations
  - R of degree k_1, cardinality n_1
  - S of degree k_2, cardinality n_2
- General form

$$R \times S = \{t[A_1,\ldots,A_{k_1}, A_{k_1+1},\ldots,A_{k_1+k_2}] \mid t[A_1,\ldots,A_{k_1}] \in R \text{ and } t[A_{k_1+1},\ldots,A_{k_1+k_2}] \in S\}$$

- The result of $R \times S$ is a relation of degree $(k_1 + k_2)$ and consists of all $(n_1 * n_2)$-tuples where each tuple is a concatenation of one tuple of R with one tuple of S.

Cartesian Product Example

EMP

ENO	ENAME	TITLE
E1	J. Doe	Elect. Eng
E2	M. Smith	Syst. Anal.
E3	A. Lee	Mech. Eng.
E4	J. Miller	Programmer
E5	B. Casey	Syst. Anal.
E6	L. Chu	Elect. Eng.
E7	R. Davis	Mech. Eng.
E8	J. Jones	Syst. Anal.

PAY

TITLE	SALARY
Elect. Eng.	55000
Syst. Anal.	70000
Mech. Eng.	45000
Programmer	60000

EMP × PAY

ENO	ENAME	EMP.TITLE	PAY.TITLE	SALARY
E1	J. Doe	Elect. Eng.	Elect. Eng.	55000
E1	J. Doe	Elect. Eng.	Syst. Anal.	70000
E1	J. Doe	Elect. Eng.	Mech. Eng.	45000
E1	J. Doe	Elect. Eng.	Programmer	60000
E2	M. Smith	Syst. Anal.	Elect. Eng.	55000
E2	M. Smith	Syst. Anal.	Syst. Anal.	70000
E2	M. Smith	Syst. Anal.	Mech. Eng.	45000
E2	M. Smith	Syst. Anal.	Programmer	60000
E3	A. Lee	Mech. Eng.	Elect. Eng.	55000
E3	A. Lee	Mech. Eng.	Syst. Anal.	70000
E3	A. Lee	Mech. Eng.	Mech. Eng.	45000
E3	A. Lee	Mech. Eng.	Programmer	60000
E8	J. Jones	Syst. Anal.	Elect. Eng.	55000
E8	J. Jones	Syst. Anal.	Syst. Anal.	70000
E8	J. Jones	Syst. Anal.	Mech. Eng.	45000
E8	J. Jones	Syst. Anal.	Programmer	60000

Types of Join

- Join is a combination of a Cartesian product followed by a selection process (using a join predicate).
  - Inner join
  - Outer join

Types of Join

- Inner join
  - Requires the joined tuples from the two operand relations to satisfy the join predicate
  - θ–join
  - Equi-join
  - Natural join

θ–Join

- General form

$$R \bowtie_{F(R.A_i, S.B_j)} S = \{t[A_1,\ldots,A_n,B_1,\ldots,B_m] \mid t[A_1,\ldots,A_n] \in R \text{ and } t[B_1,\ldots,B_m] \in S \text{ and } F(R.A_i, S.B_j) \text{ is true}\}$$

where

- R, S are relations, t is a tuple variable
- $F(R.A_i, S.B_j)$ is a formula defined as that of selection
- $R \bowtie_F S = \sigma_F(R \times S)$

Natural Join

- Equi-join
  - The formula F only contains equality as the arithmetic operator
  - $R \bowtie_{R.A=S.B} S$
- Natural join
  - Equi-join of two relations R and S over attributes common to both R and S and projecting out one copy of those attributes
  - $R \bowtie S = \Pi_{R \cup S} \sigma_F (R \times S)$

Natural Join Example

EMP

ENO	ENAME	TITLE
E1	J. Doe	Elect. Eng
E2	M. Smith	Syst. Anal.
E3	A. Lee	Mech. Eng.
E4	J. Miller	Programmer
E5	B. Casey	Syst. Anal.
E6	L. Chu	Elect. Eng.
E7	R. Davis	Mech. Eng.
E8	J. Jones	Syst. Anal.

PAY

TITLE	SALARY
Elect. Eng.	55000
Syst. Anal.	70000
Mech. Eng.	45000
Programmer	60000

EMP $\bowtie$ PAY

ENO	ENAME	TITLE	SALARY
E1	J. Doe	Elect. Eng.	55000
E2	M. Smith	Analyst	70000
E3	A. Lee	Mech. Eng.	45000
E4	J. Miller	Programmer	60000
E5	B. Casey	Syst. Anal.	70000
E6	L. Chu	Elect. Eng.	55000
E7	R. Davis	Mech. Eng.	45000
E8	J. Jones	Syst. Anal.	70000

Join is over the common attribute TITLE

Types of Join

- Outer join
  - Ensures that tuples from one or both relations that do not satisfy the join predicate still appear in the final result with other relation's attribute values set to Null
  - Left outer join ⟕
  - Right outer join ⟖
  - Full outer join ⟗

Semijoin

- The semijoin of relation R, defined over the set of attributes A, by relation S, defined over the set of attributes B, is the subset of the tuples of R that participate in the join of R with S.
- Derivation

$$R \ltimes_F S = \Pi_A(R \bowtie_F S) \quad = \Pi_A(R) \bowtie \Pi_{A \cap B}(S) = R \bowtie_F \Pi_{A \cap B}(S)$$

where

- R, S are relations
- A is a set of attributes

Semijoin Example

$\text{EMP} \ltimes_{\text{EMP.TITLE=PAY.TITLE}} \text{PAY}$

ENO	ENAME	TITLE
E1	J. Doe	Elect. Eng.
E2	M. Smith	Analyst
E3	A. Lee	Mech. Eng.
E4	J. Miller	Programmer
E5	B. Casey	Syst. Anal.
E6	L. Chu	Elect. Eng.
E7	R. Davis	Mech. Eng.
E8	J. Jones	Syst. Anal.

Division

- The division of relation R of degree r with relation S of degree s (where $r>s$ and s>0) is the set of (r-s)-tuples t such that for all s-tuples u in S, the tuple tu is in R.
- Derivation

$$R \div S = \Pi_Y(R) - \Pi_Y((\Pi_Y(R) \times S) - R)$$

where Y is the set of attributes of R that are not in S.

Division Example

ASG'

ENO	PNO	PNAME	BUDGET
E1	P1	Instrumentation	150000
E2	P1	Instrumentation	150000
E2	P2	Database Develop.	135000
E3	P3	CAD/CAM	250000
E3	P4	Maintenance	310000
E4	P2	Database Develop.	135000
E5	P2	Database Develop.	135000
E6	P4	Maintenance	310000
E7	P3	CAD/CAM	250000
E8	P3	CAD/CAM	250000

PROJ'

PNO	PNAME	BUDGET
P3	CAD/CAM	250000
P4	Maintenance	310000

(ASG' ÷ PROJ')

ENO
E3

Relational Calculus

- Specify the properties that the result should hold
  - Tuple relational calculus
  - Domain relational calculus

Tuple Relational Calculus

- Query of the form $\{t \mid F\{t\}\}$ where
  - t is a tuple variable
  - F is a well-formed formula

SQL

- Find the names of employees working on the CAD/CAM project.

```
SELECT    EMP.NAME
FROM      EMP, ASG, PROJ
WHERE     EMP.NO = ASG.NO
AND       ASG.PNO = PROJ.PNO
AND       PROJ.PNAME = "CAD/CAM"
```

SQL

- Selection

```
SELECT   *
FROM     Relation name
WHERE    Predicate F
```

```
SELECT   ENAME
FROM     EMP
WHERE    TITLE = "ELECT. ENG."
```

SQL

- Projection

```
SELECT    Attribute list
FROM      Relation name
```

```
SELECT    ENAME, TITLE
FROM      EMP
```

SQL

- Join

```
SELECT    *
FROM      Relation name 1, Relation name 2
WHERE     Predicate F
```

```
SELECT    *
FROM      EMP, PAY
WHERE     EMP.TITLE = PAY.TITLE
```

Domain Relational Calculus

- Query of the form $x_1, x_2, \ldots, x_n \mid F(x_1, x_2, \ldots, x_n)$ where
  - F is a well-formed formula in which $x_1, x_2, \ldots, x_n$ are the free domain variables
- The user formulates a query by providing a possible example of the answer.
- By supplying keywords into the domains (columns) the user specify a query.

QBE

- Find the names of employees working on the CAD/CAM project.

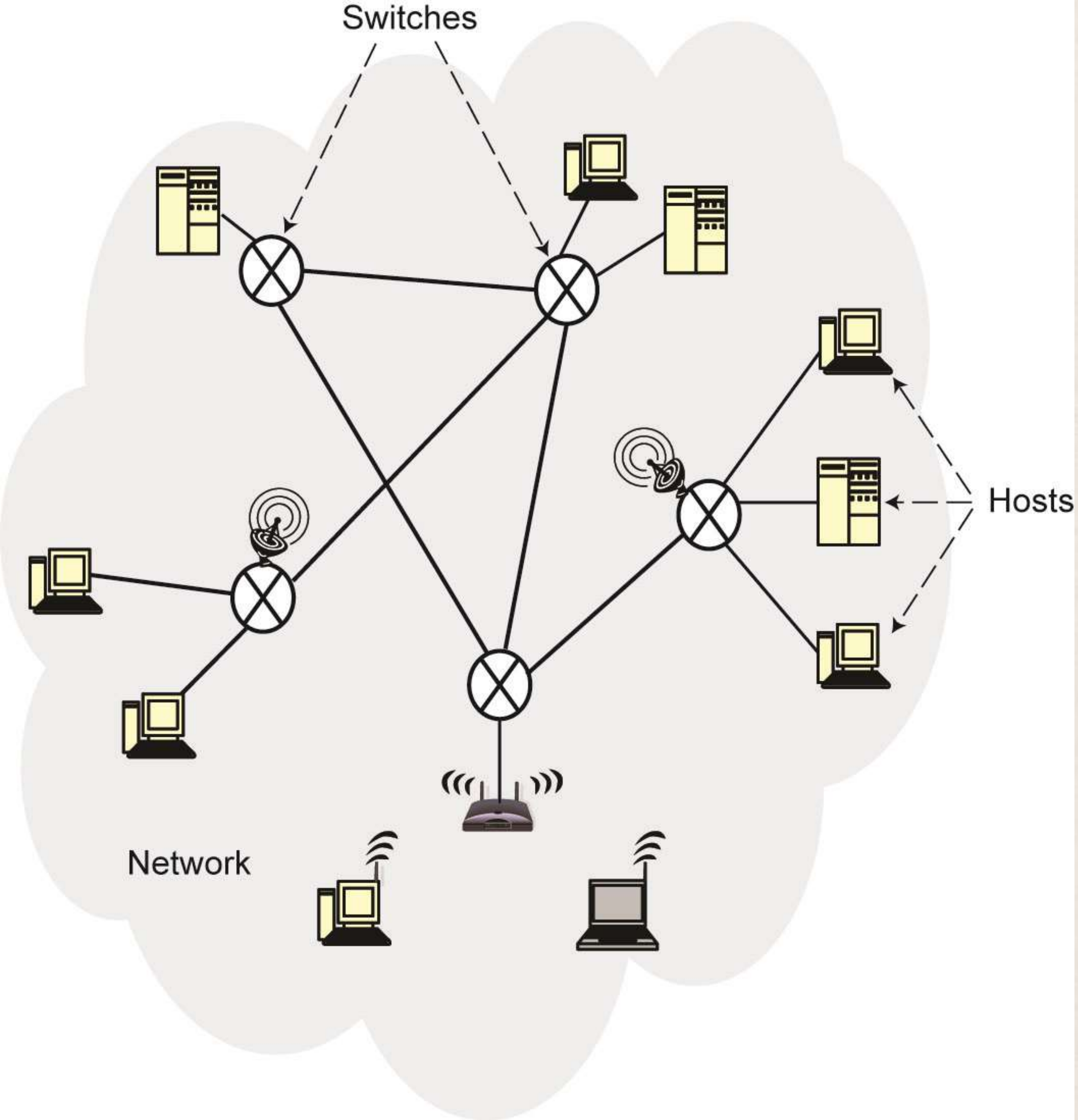
EMP	ENO	ENAME	TITLE
	E2	P.	

ASG	ENO	PNO	RESP	DUR
	E2	P3		

PROJ	PNO	PNAME	BUDGET
	P3	CAD/CAM	

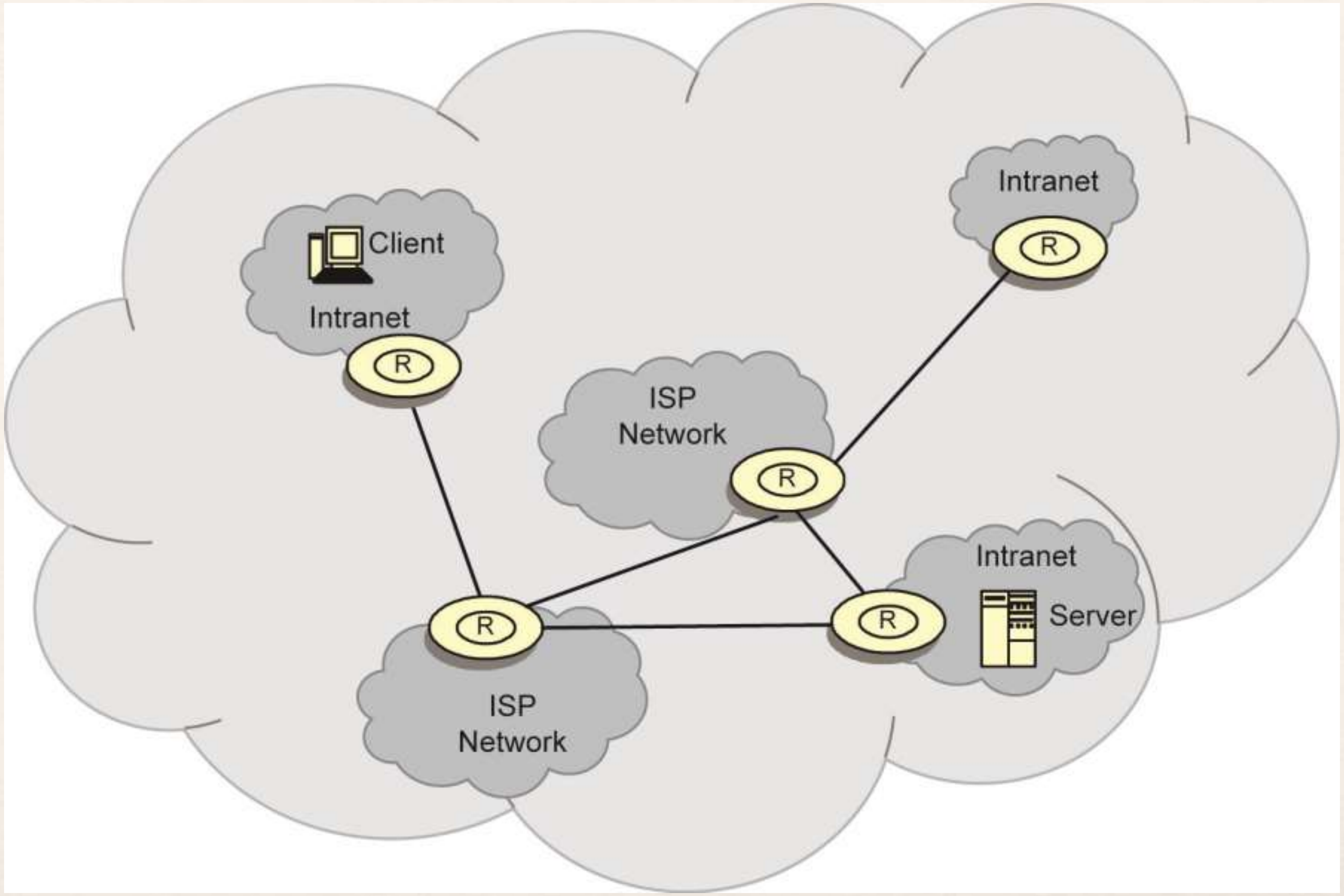
Computer Network

- An interconnected collection of autonomous computers that are capable of exchanging information among themselves.
- Components
  - Hosts (end systems, sites, nodes)
  - Switches
  - Communication links



Internet

- Network of networks



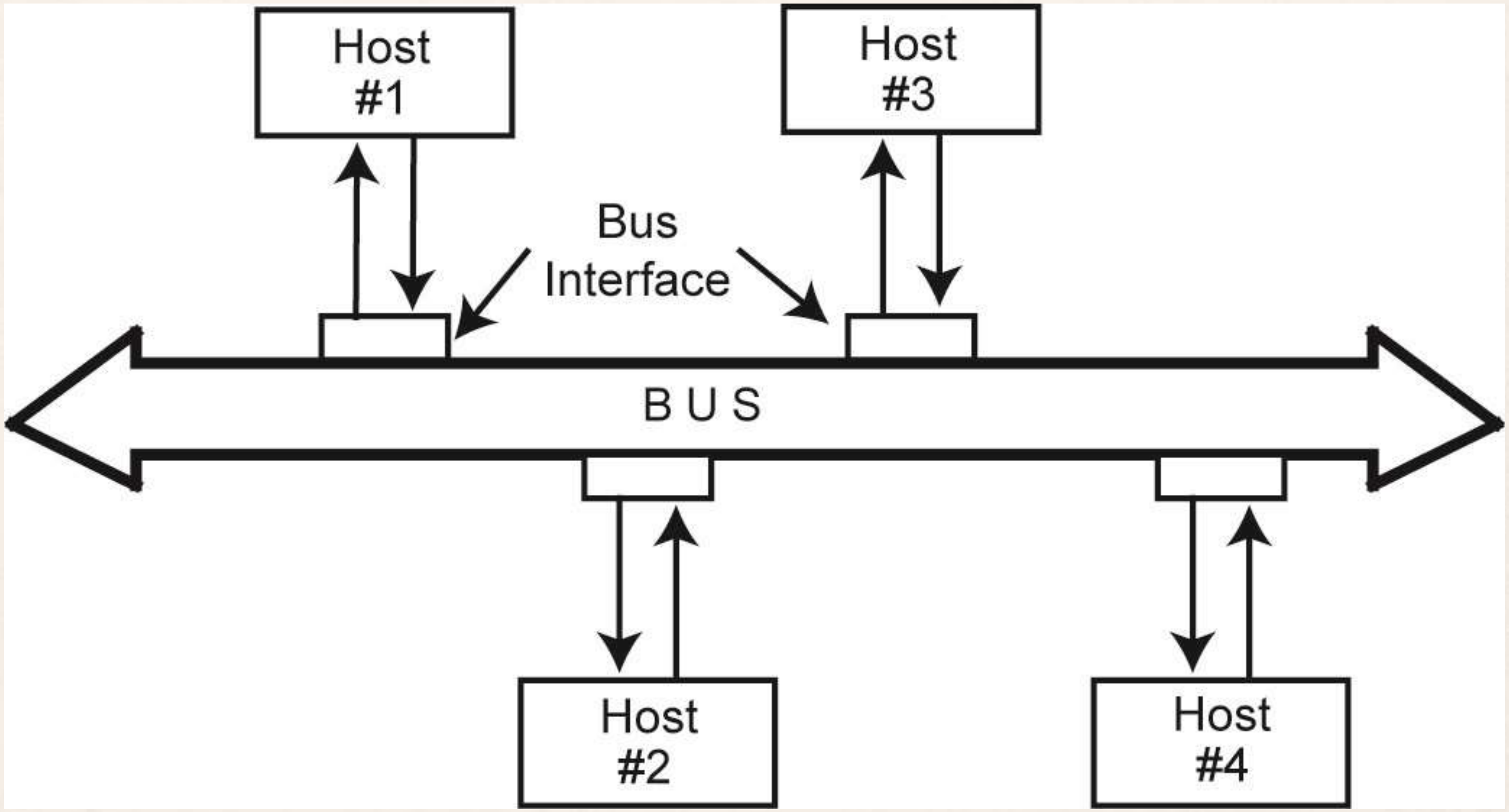
Types of Networks

- According to scale (geographic distribution)
  - Wide are network (WAN)
    - Distance between any two nodes > 20km and can go as high as thousands of km
    - Long delays due to distance traveled
    - Heterogeneity of transmission media
    - Speeds of 150Mbps to 10Gbps (STM-640 on the backbone)
  - Local area network (LAN)
    - Limited in geographic scope (usually < 2km)
    - Speeds 10-1000 Mbps
    - Short delays and low noise
  - Metropolitan area network (MAN)
    - In between LAN and WAN

Types of Networks

- According to topology
  - Irregular
    - No regularity in the interconnection – e.g., Internet
  - Mesh (complete)
  - Bus
    - Ethernet
    - Using Carrier Sense Multiple Access with Collision Detection (CSMA/CD)
      - Listen before and while you transmit
  - Ring
  - Star

Bus network



Communication Alternatives

- Twisted pair
- Coaxial
- Fiber optic

- Satellite
- Microwave
- Wireless LANs

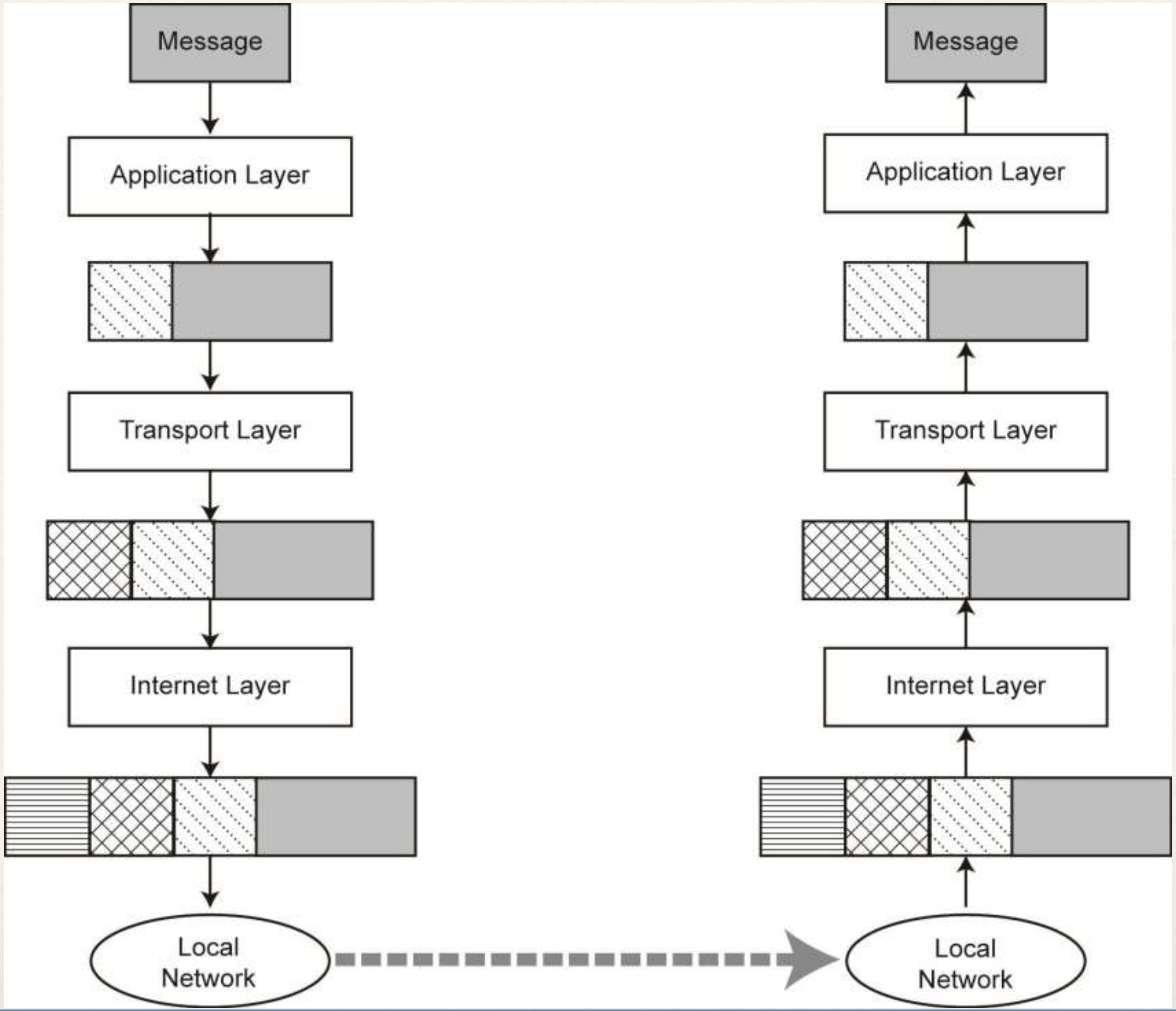
Data Communication

- Hosts are connected by links, each of which can carry one or more channels
- Link: physical entity; channel: logical entity
- Digital signal versus analog signal
- Capacity – bandwidth
  - The amount of information that can be transmitted over the channel in a given time unit

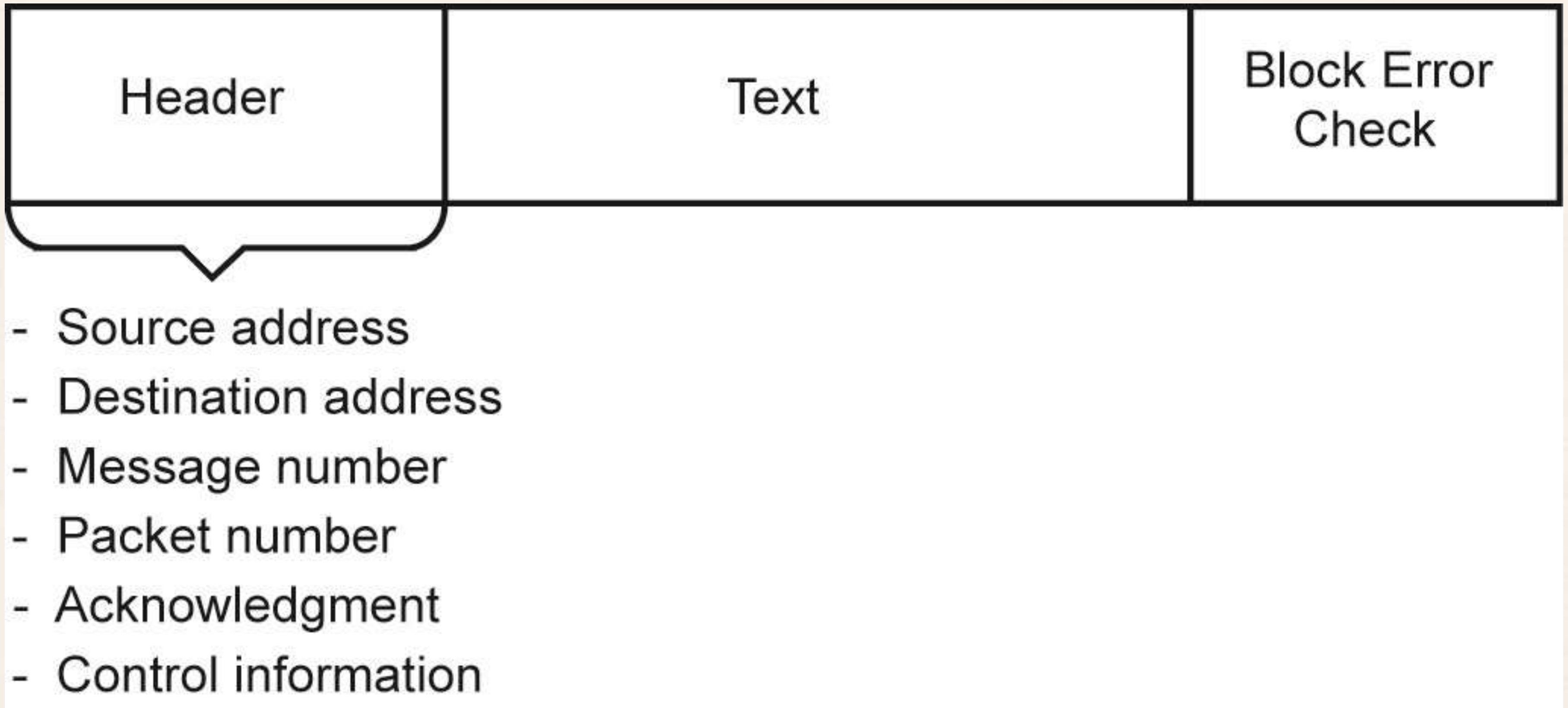
Communication Protocols

- Software that ensures error-free, reliable and efficient communication between hosts
- Layered architecture – hence protocol stack or protocol suite
- TCP/IP is the best-known one
  - Used in the Internet

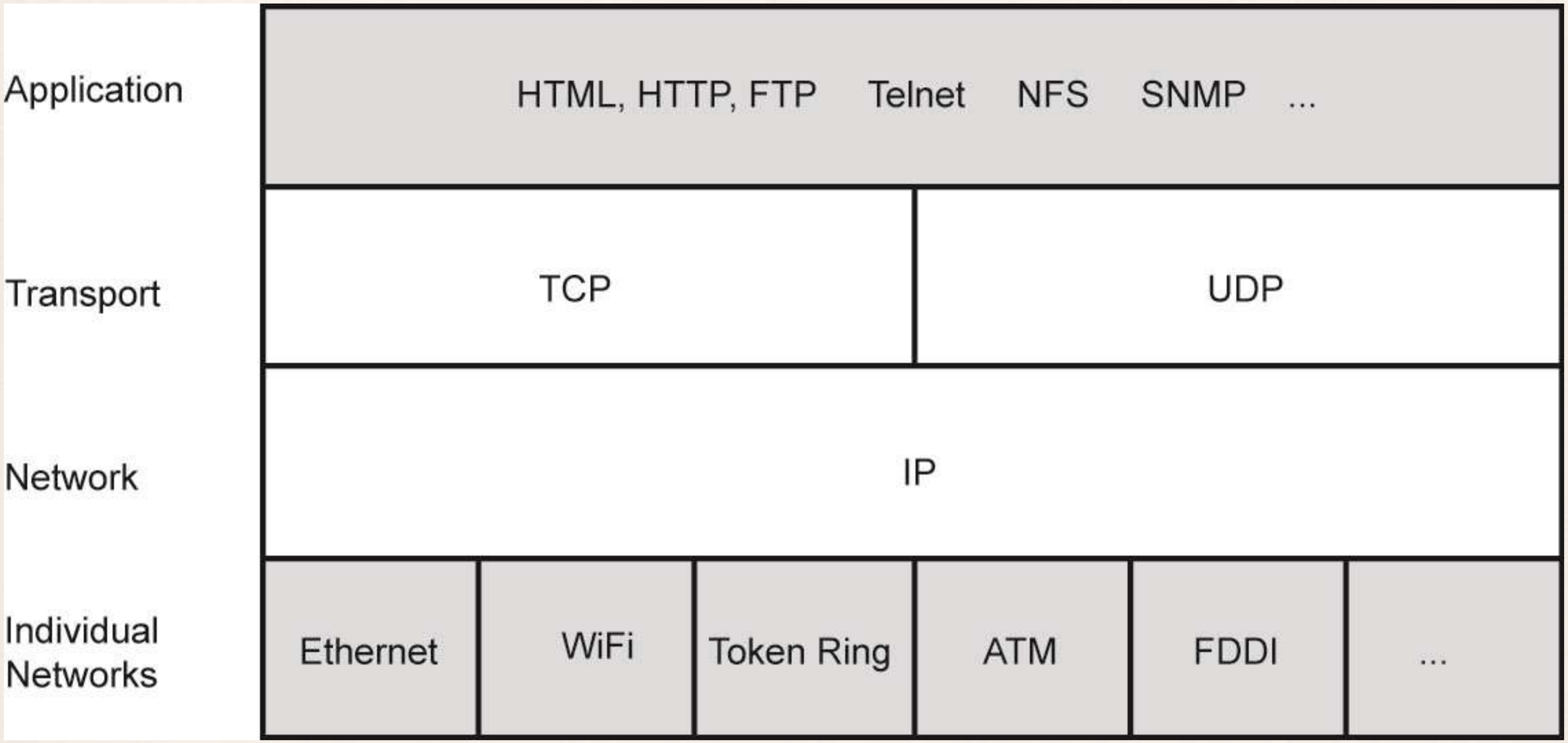
Message Transmission using TCP/IP



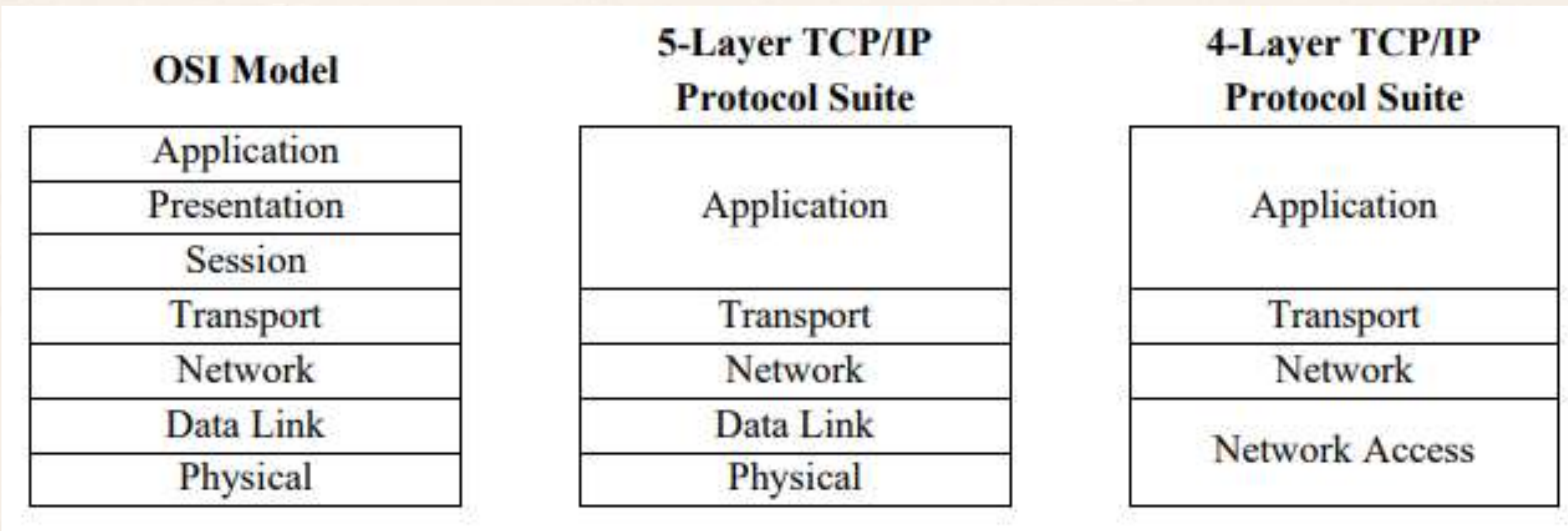
Frame Format



TCP/IP Protocol Stack



Protocol Suites



Programming Interfaces

- Publish-Subscribe
- RPC
  - https://docs.oracle.com/javase/tutorial/rmi/index.html
- Sockets
  - https://docs.oracle.com/javase/tutorial/networking/sockets/index.html
  - https://docs.oracle.com/javase/tutorial/essential/concurrency/procthread.html