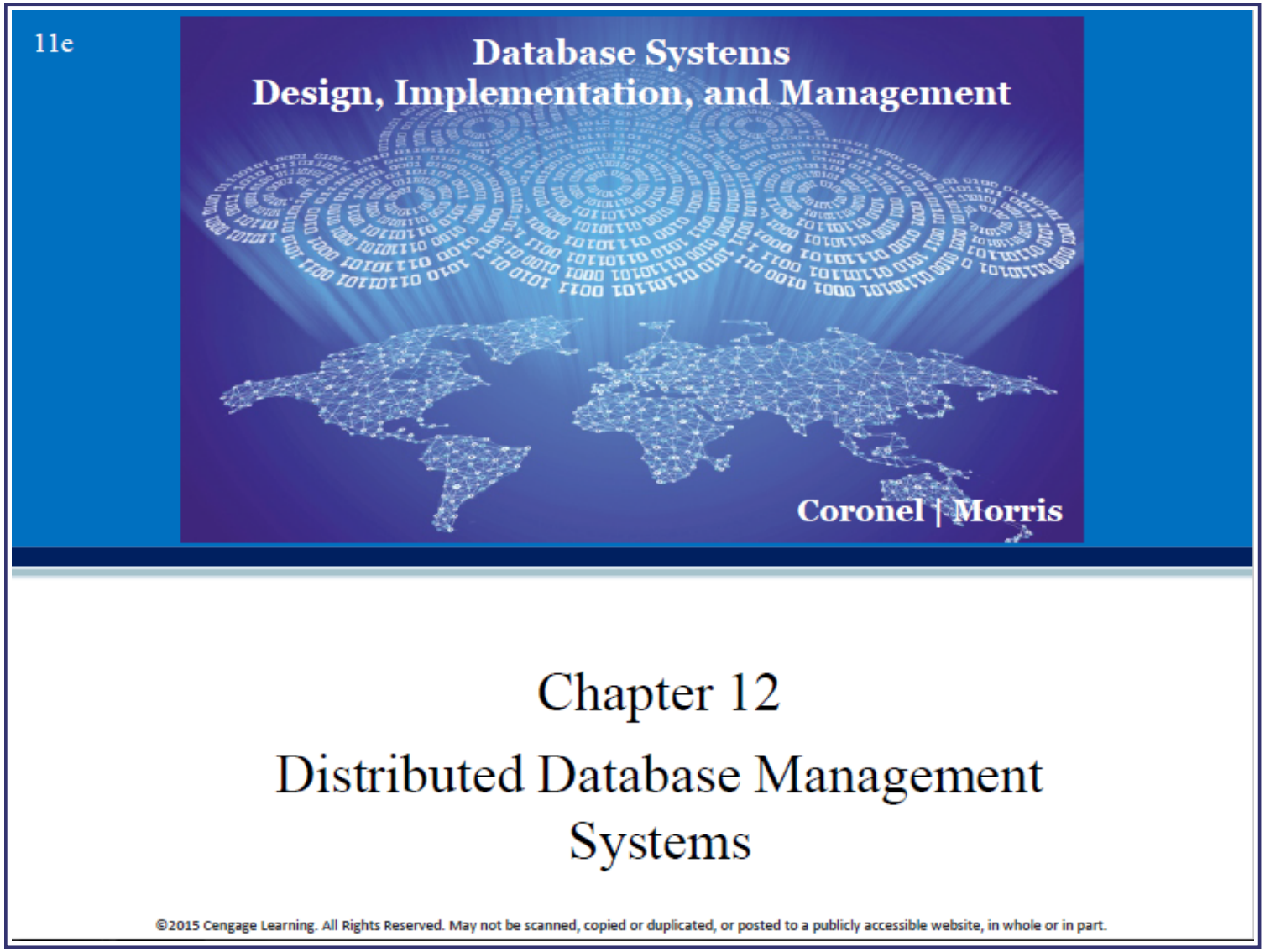
Distributed DBs

what is distributed?

how are transactions managed?

what is the architecture?

Ch.12


11e
Database Systems
Design, Implementation, and Management
Coronel | Morris
Chapter 12
Distributed Database Management Systems
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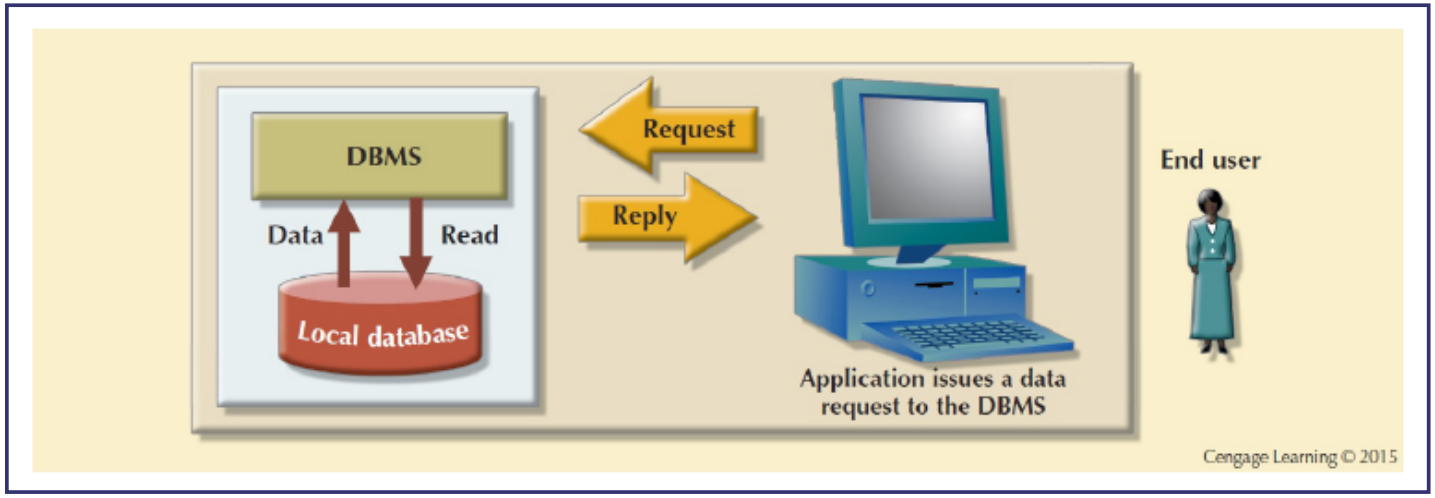
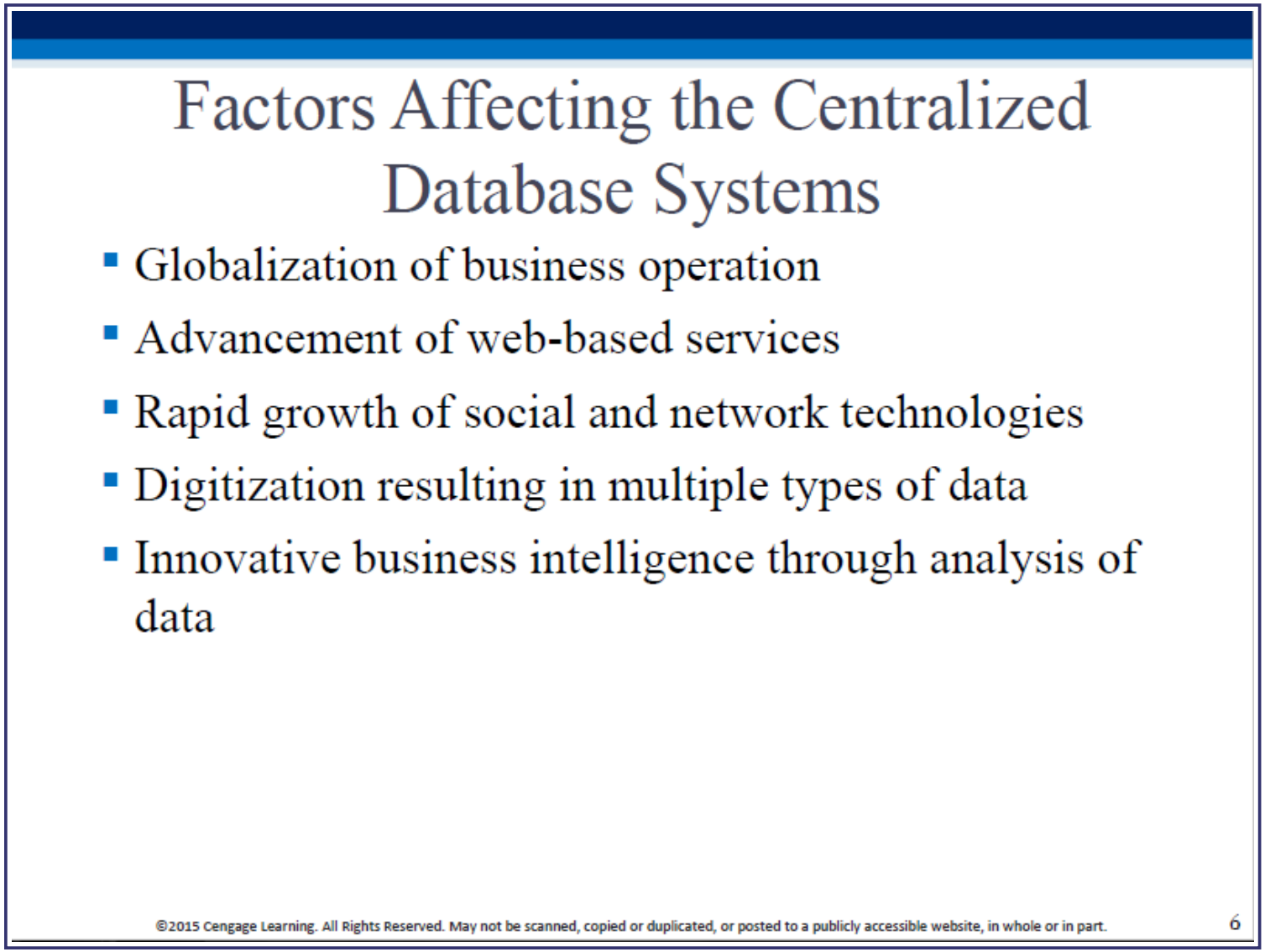
'Centralized' DBs - no longer popular/useful

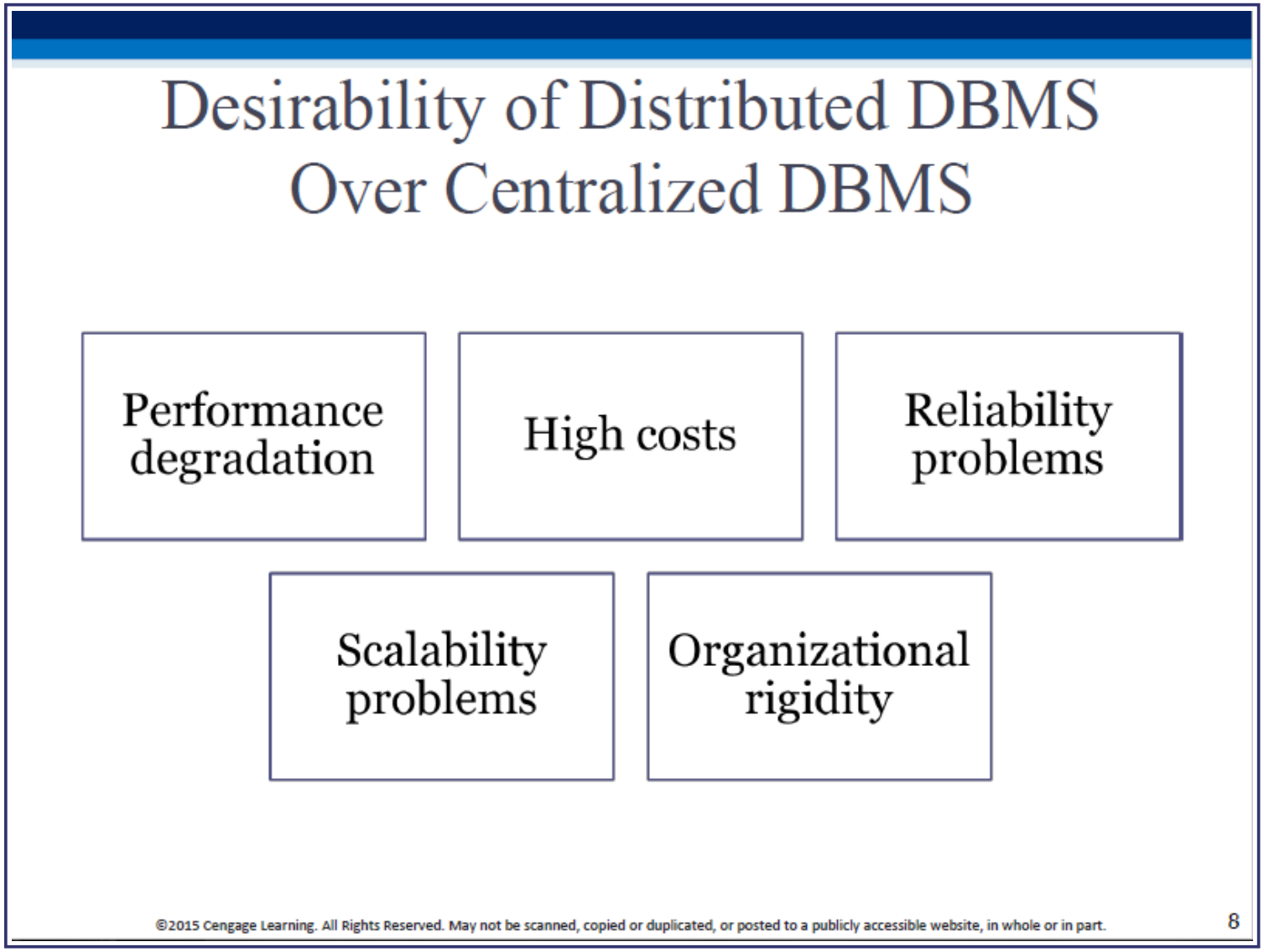




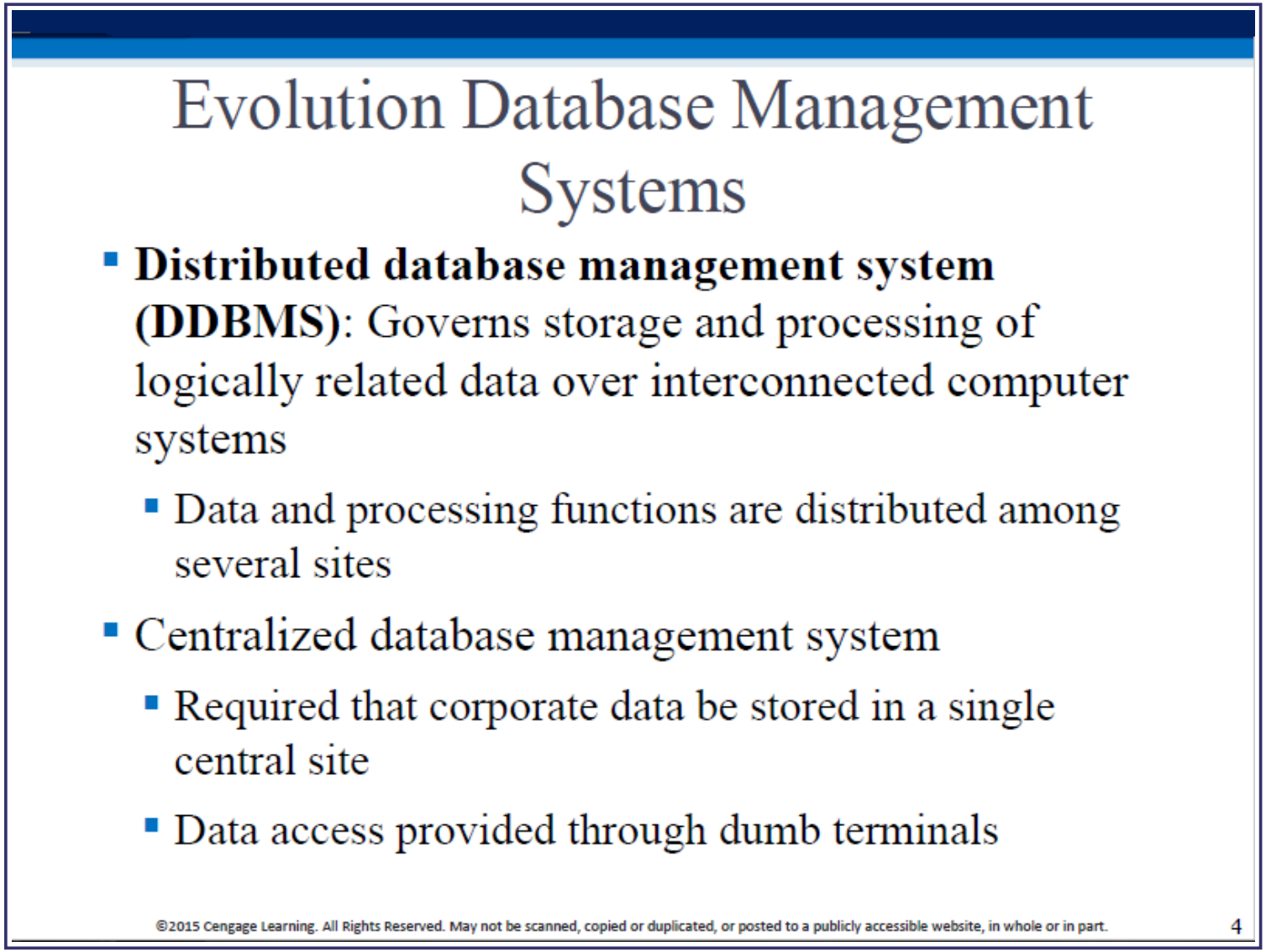
Two factors in particular, necessitated change:

- rapid, ad-hoc access to data was needed ['Internet speed' decision-making]
- distributed data access was needed, to serve dispersed business units [globalization]

So now we have **D**DBMSs - **distributed** DBMSs.



Distributed DBs - almost ALL (web-based)!



Factors That Aided DDBMS to Cope With Technological Advancement

- Acceptance of Internet as a platform for business
- Mobile wireless revolution
- Usage of application as a service
- Focus on mobile business intelligence

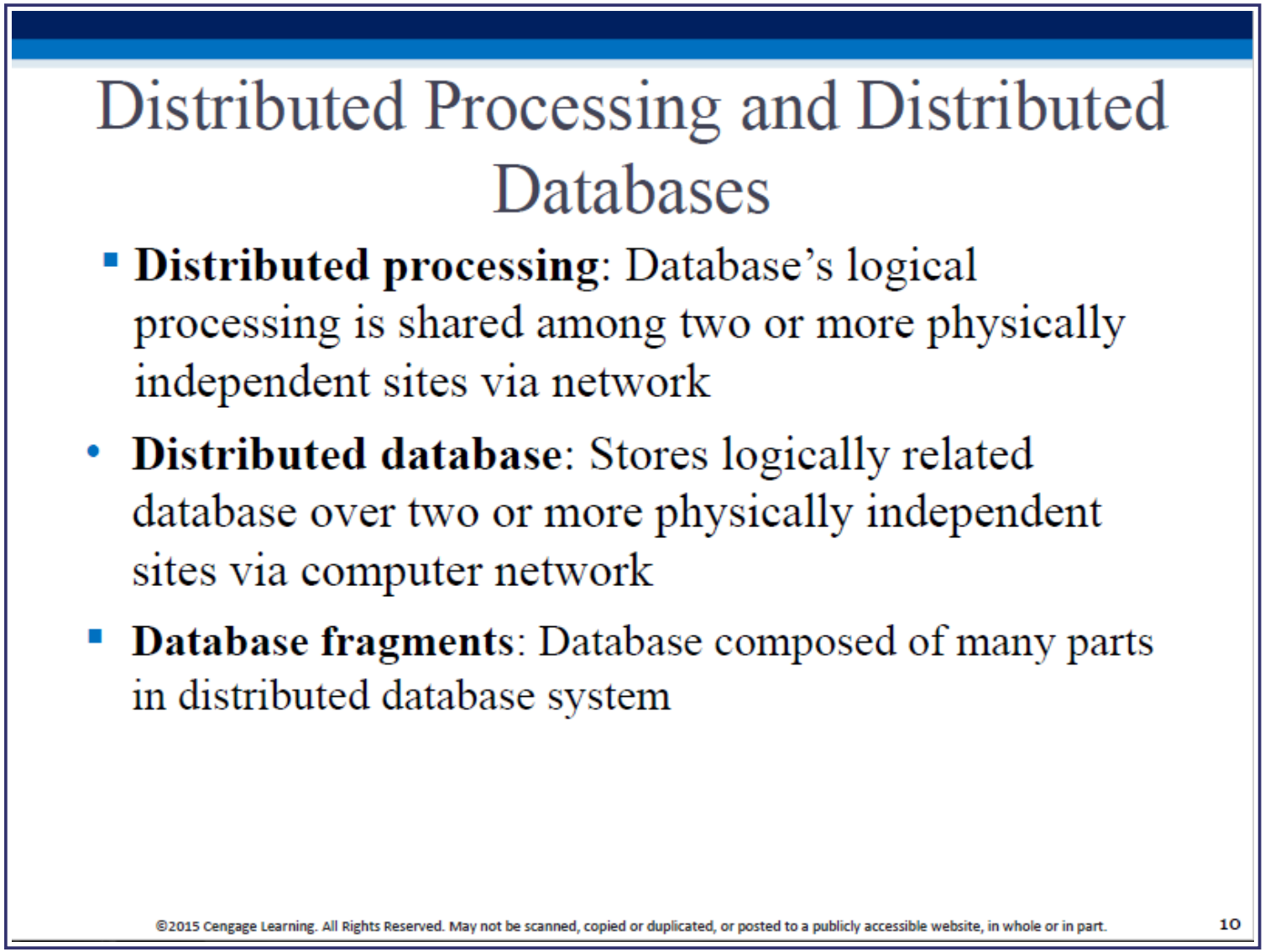
7

Advantages and Disadvantages of DDBMS

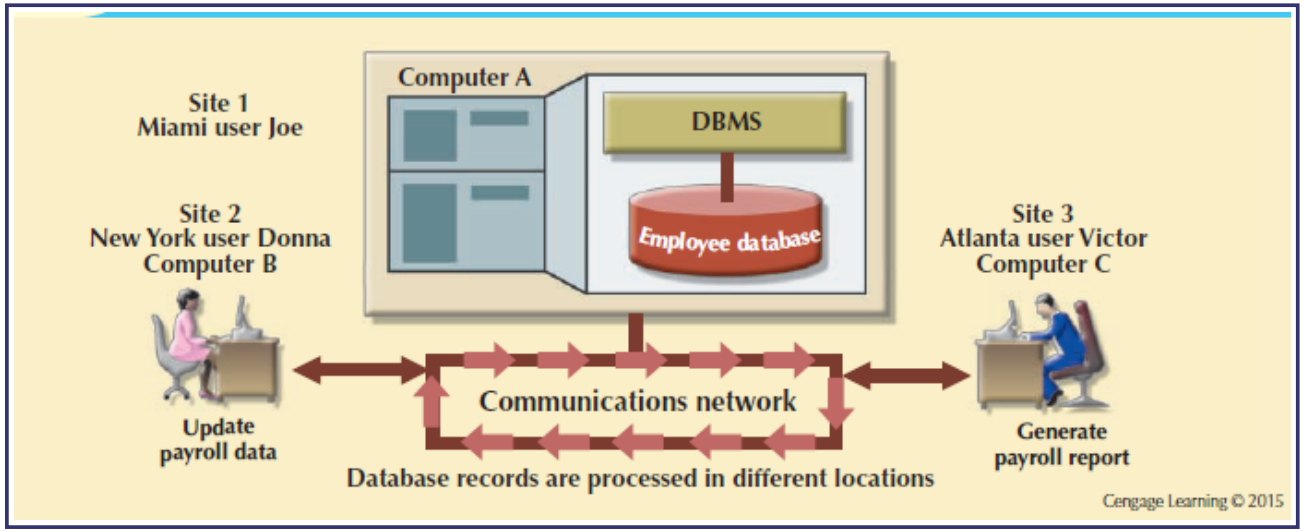
Advantages	Disadvantages
• Data are located near greatest demand site • Faster data access and processing • Growth facilitation • Improved communications • Reduced operating costs • User-friendly interface • Less danger of a single-point failure • Processor independence	• Complexity of management and control • Technological difficulty • Security • Lack of standards • Increased storage and infrastructure requirements • Increased training cost • Costs incurred due to the requirement of duplicated infrastructure

9

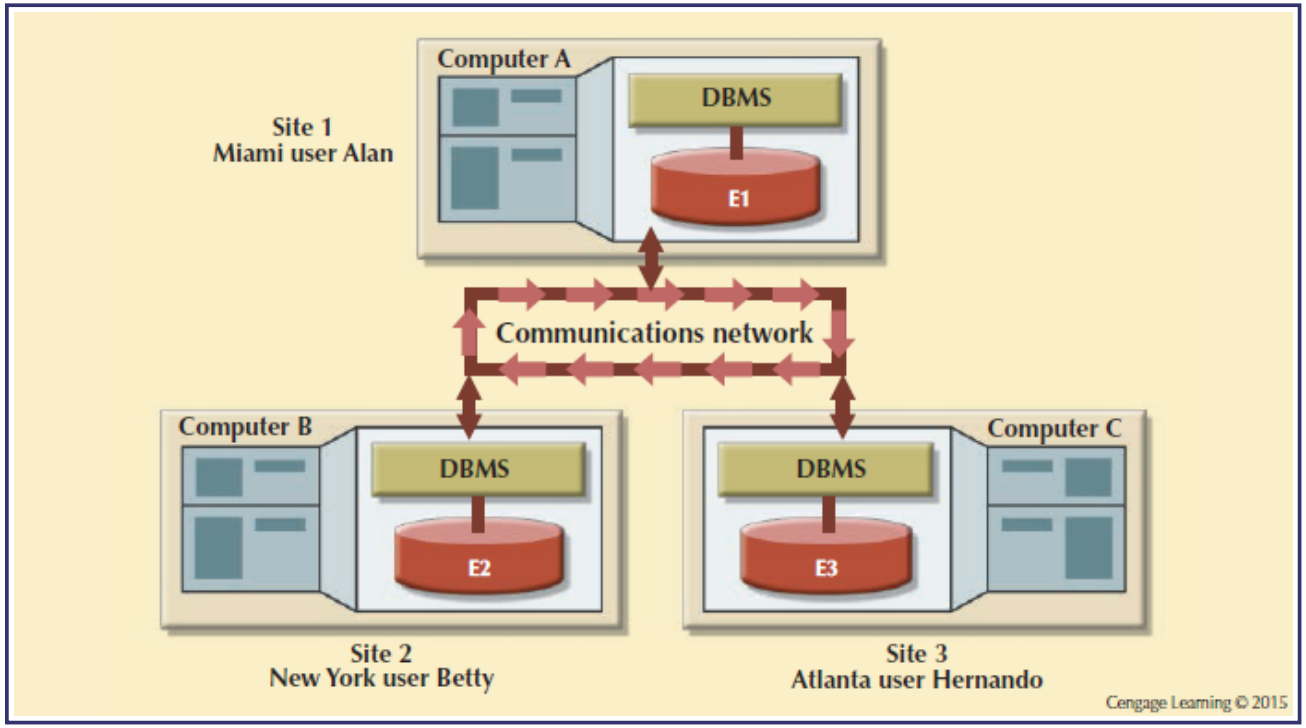
Distributed *processing* vs distributed *databases*



Distributed *processing*

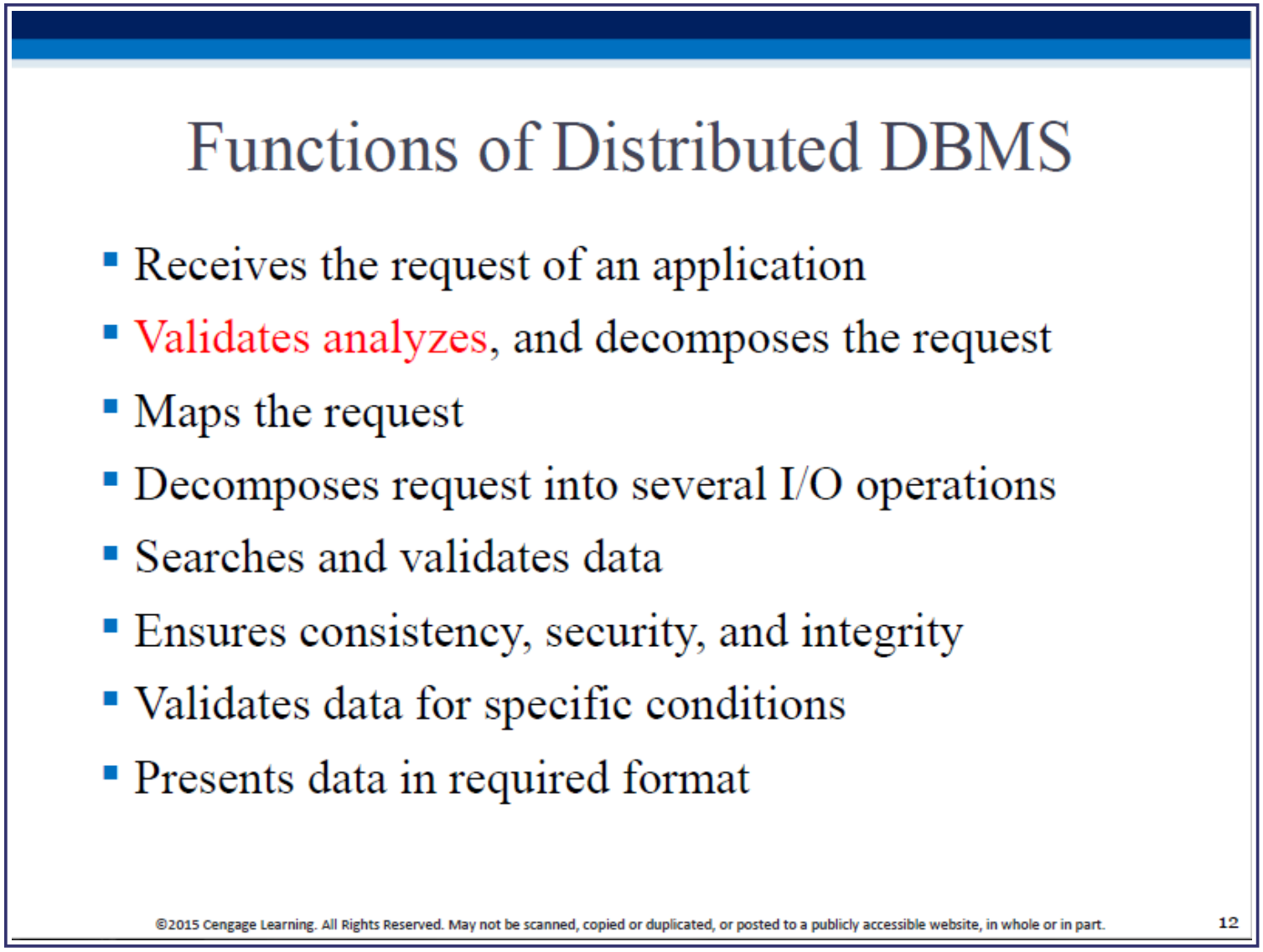


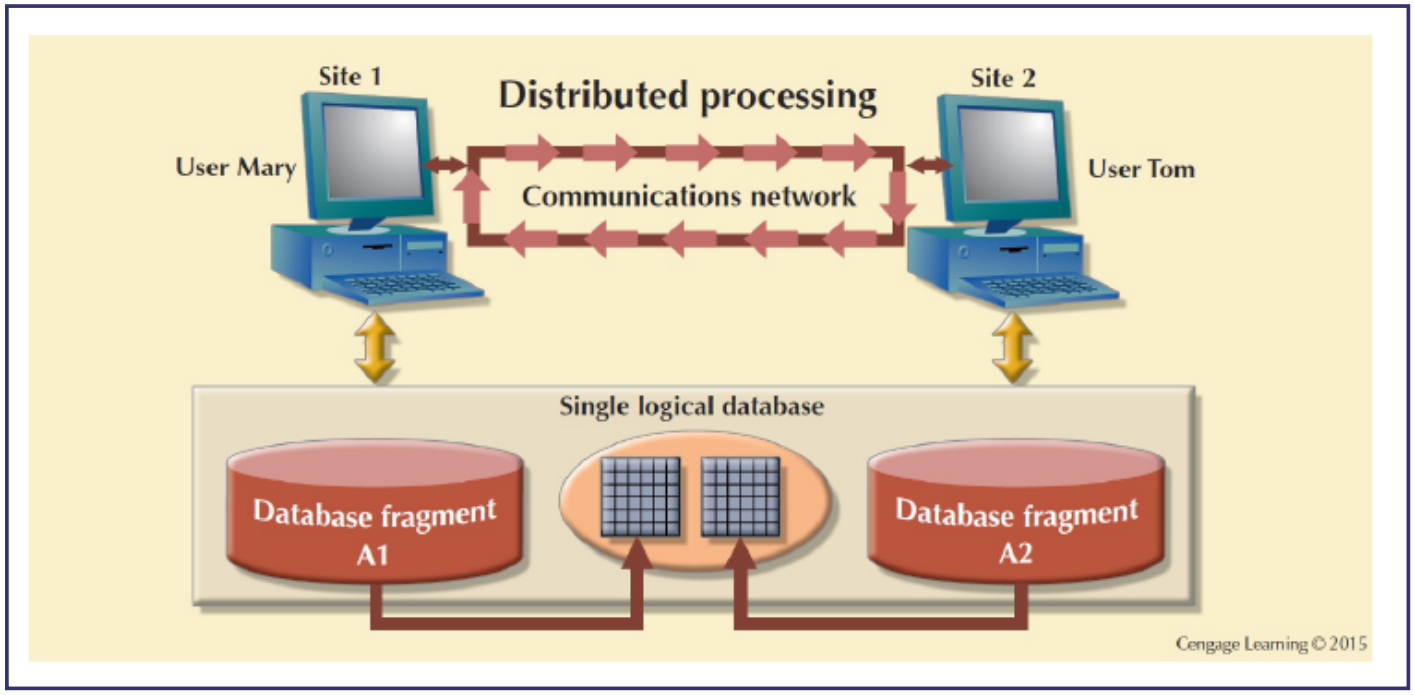
Distributed *databases*



Fully distributed DBMSs: functions

Distributed processing AND data storage -> 'fully' distributed.





Two fragments, two sites - but each user thinks they have a single (their own) local version (transparent access).

TP(TM) vs DP(DM)

DDBMS Components

- Computer workstations or remote devices
- Network hardware and software components
- Communications media
- **Transaction processor (TP):** Software component of a system that requests data
- Known as **transaction manager (TM)** or **application processor (AP)**
- **Data processor (DP)** or **data manager (DM)**
- Software component on a system that stores and retrieves data from its location

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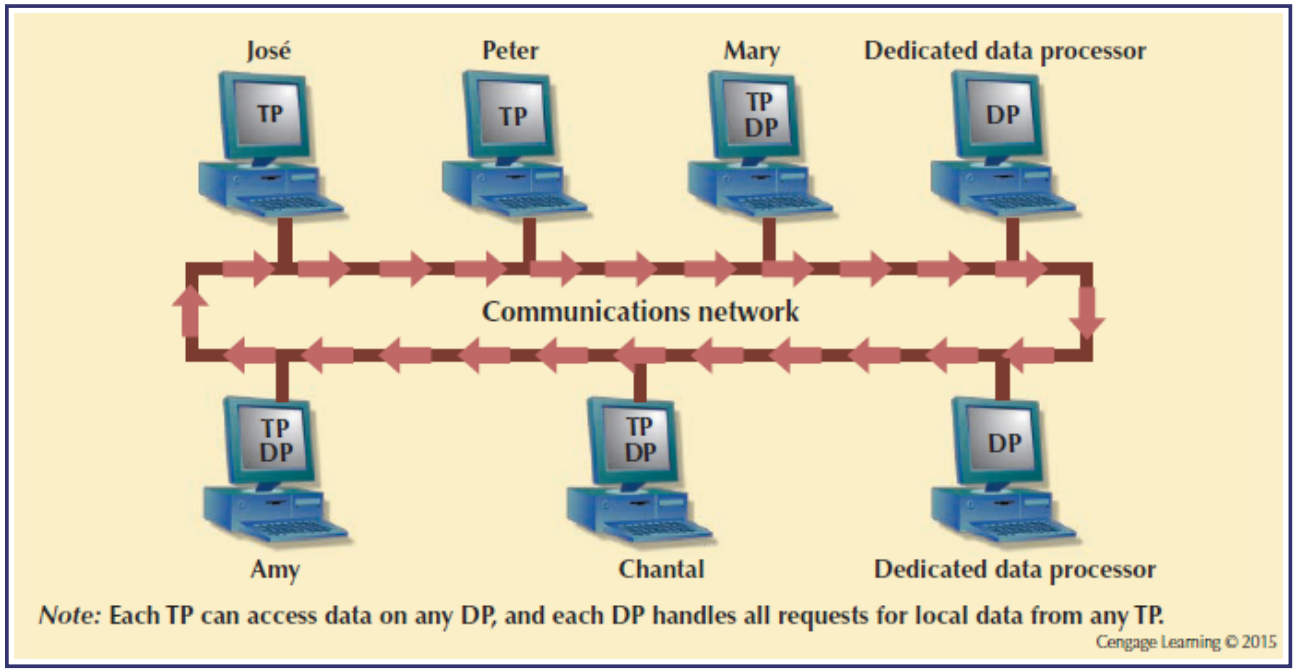


A set of protocols is used by the DDBMS, to enable the TPs and DPs to communicate with each other.

TP: Transaction Processor - receives data requests (from an application), and requests data (from a DP); also known as AP (Application Processor) or TM (Transaction Manager). A TP is what fulfills data requests on behalf of a transaction.

DP: Data Processor - receives data requests from a TP (in general, multiple TPs can request data from a single DP), retrieves and returns the requested data; also known as DM (Data Manager).

Data and processing distribution: 3 variations

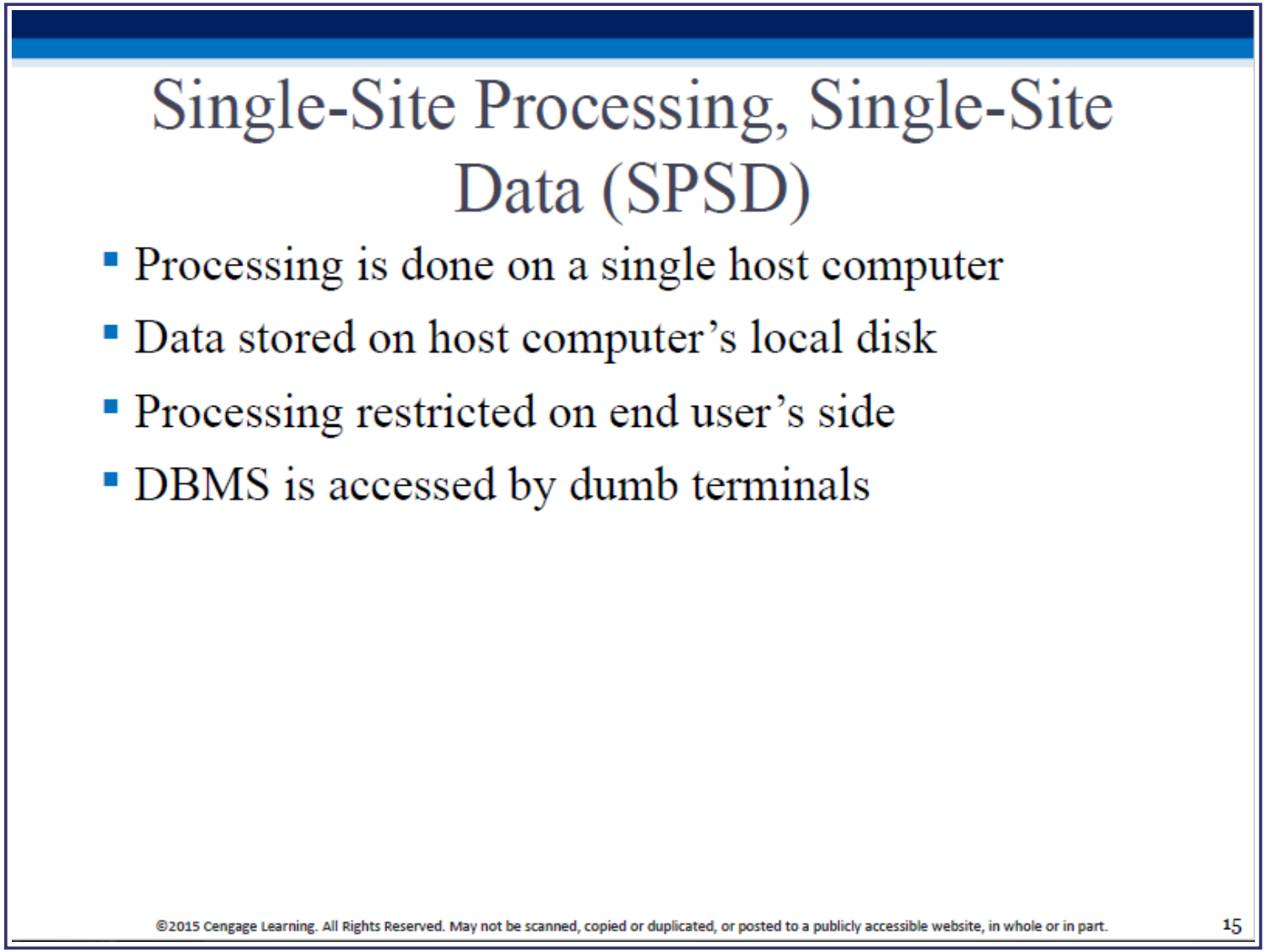
12.6 Levels of Data and Process Distribution

Current database systems can be classified on the basis of how process distribution and data distribution are supported. For example, a DBMS may store data in a single site (using a centralized DB) or in multiple sites (using a distributed DB), and may support data processing at one or more sites. Table 12.2 uses a simple matrix to classify database systems according to data and process distribution. These types of processes are discussed in the sections that follow.

TABLE 12.2 Database Systems: Levels of Data and Process Distribution

[redacted]	SINGLE-SITE DATA	MULTIPLE-SITE DATA
Single-site process	Host DBMS	Not appl[redacted]e (Requires [redacted]iple processes)
Multiple-site process	File server Client/server DBMS (LAN DBMS)	Fully distributed Client/server DDBMS

SP/SD


Single-Site Processing, Single-Site Data (SPSD)
Processing is done on a single host computer
Data stored on host computer's local disk
Processing restricted on end user's side
DBMS is accessed by dumb terminals
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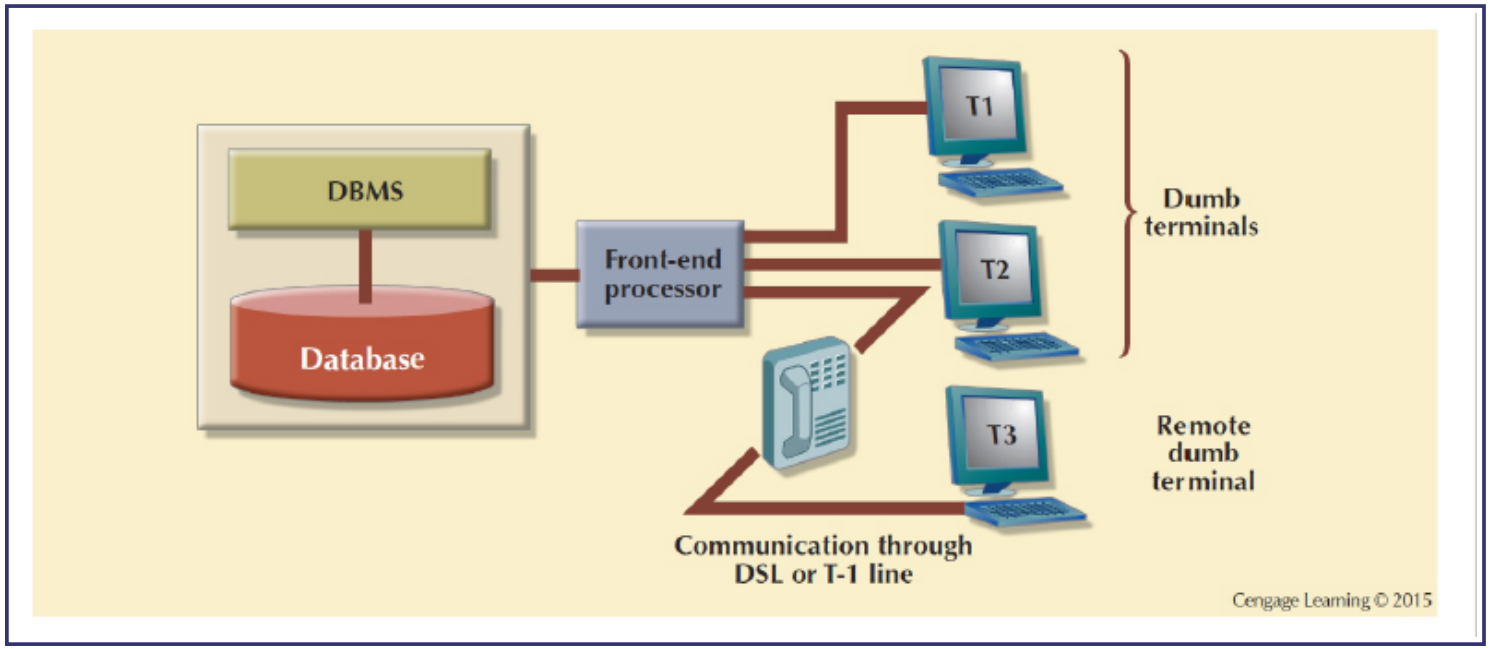
15


DBMS
Database
Front-end processor
T1
T2
T3
Dumb terminals
Remote dumb terminal
Communication through DSL or T-1 line
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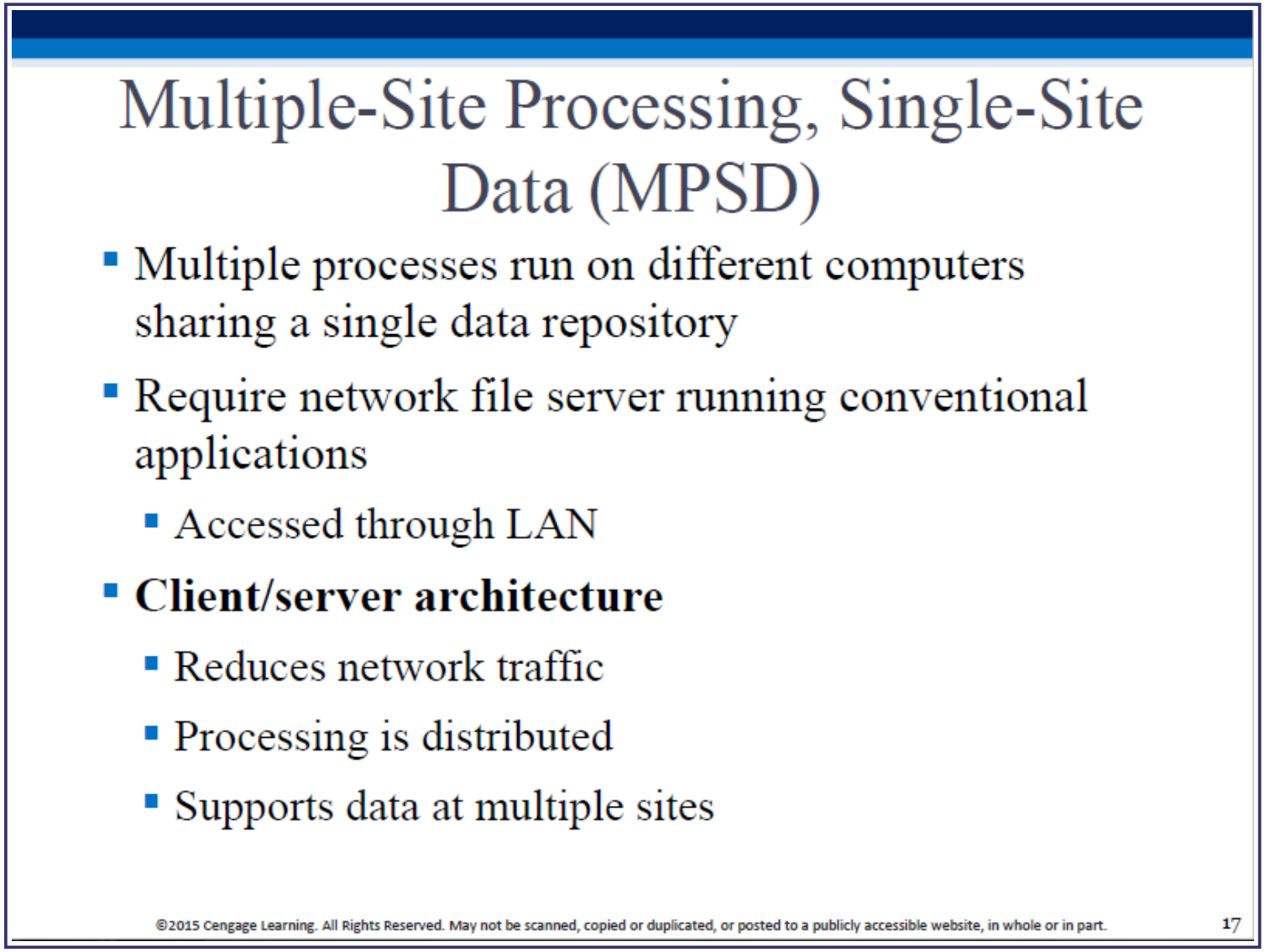
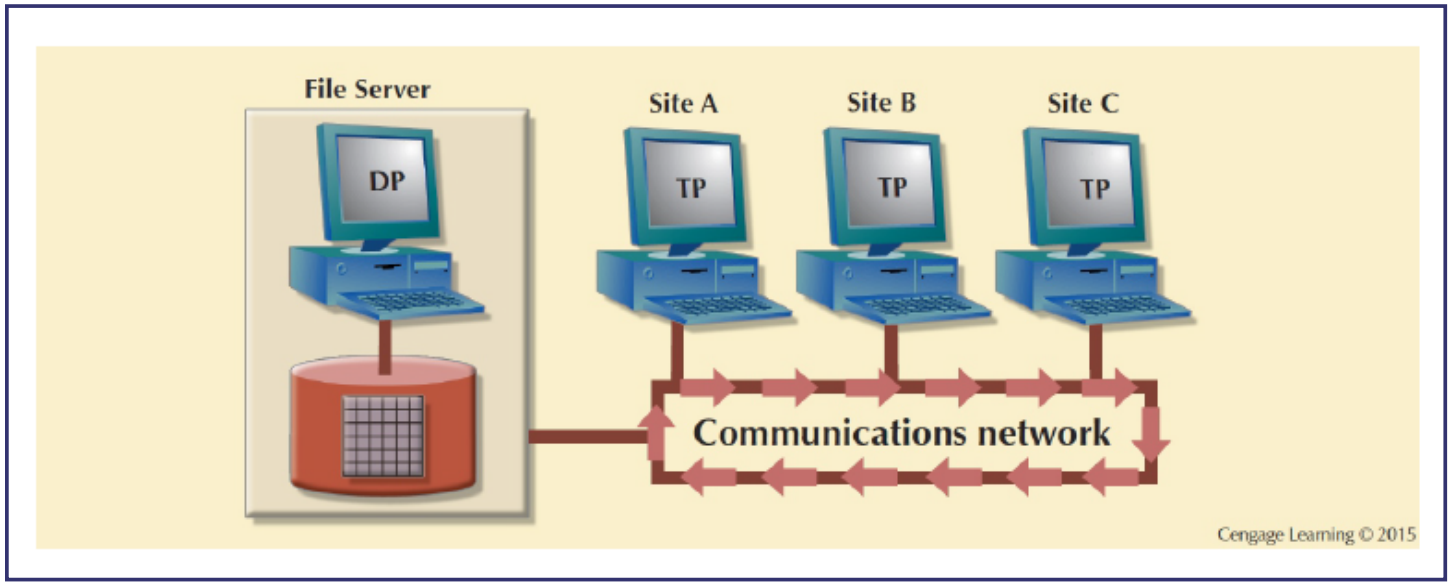
MP/SD [note: no SP/MD!]



Not truly 'distributed' (data I/O is centralized).


File Server
DP
Site A
TP
Site B
TP
Site C
TP
Communications network
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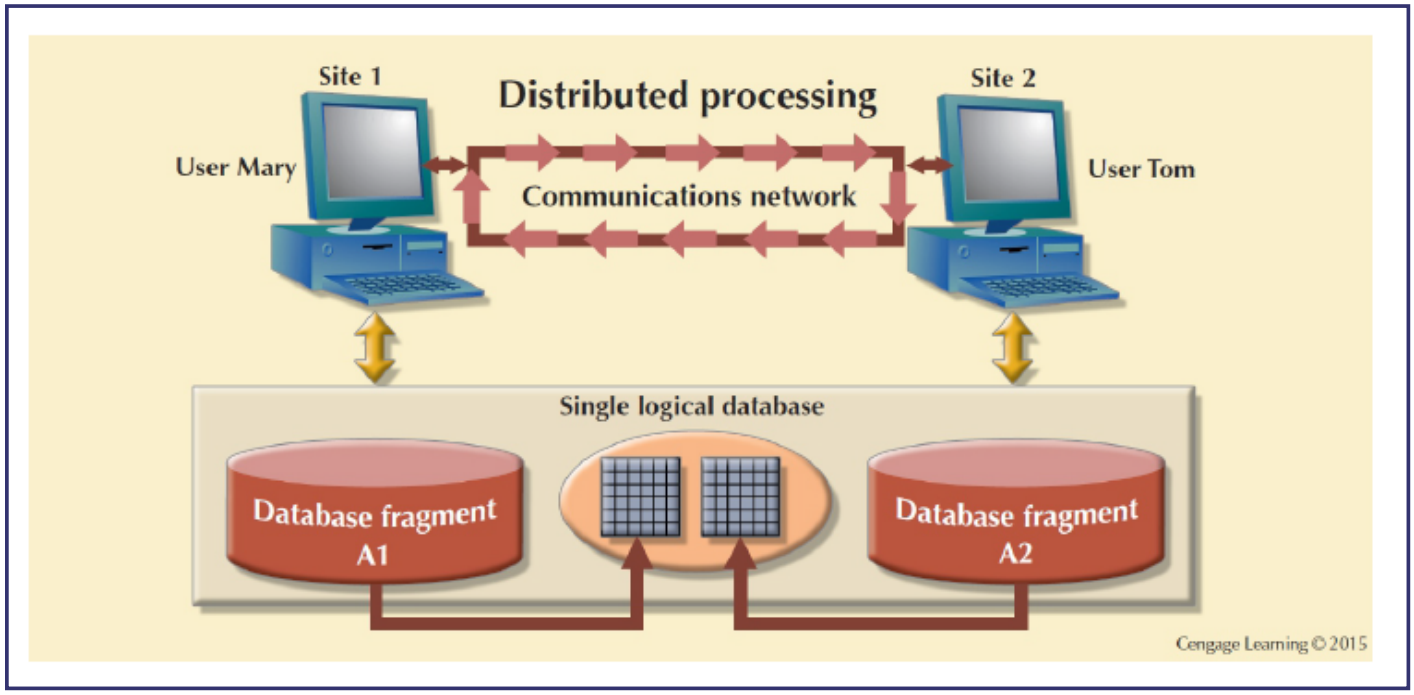
MP/MD ['fully distributed']

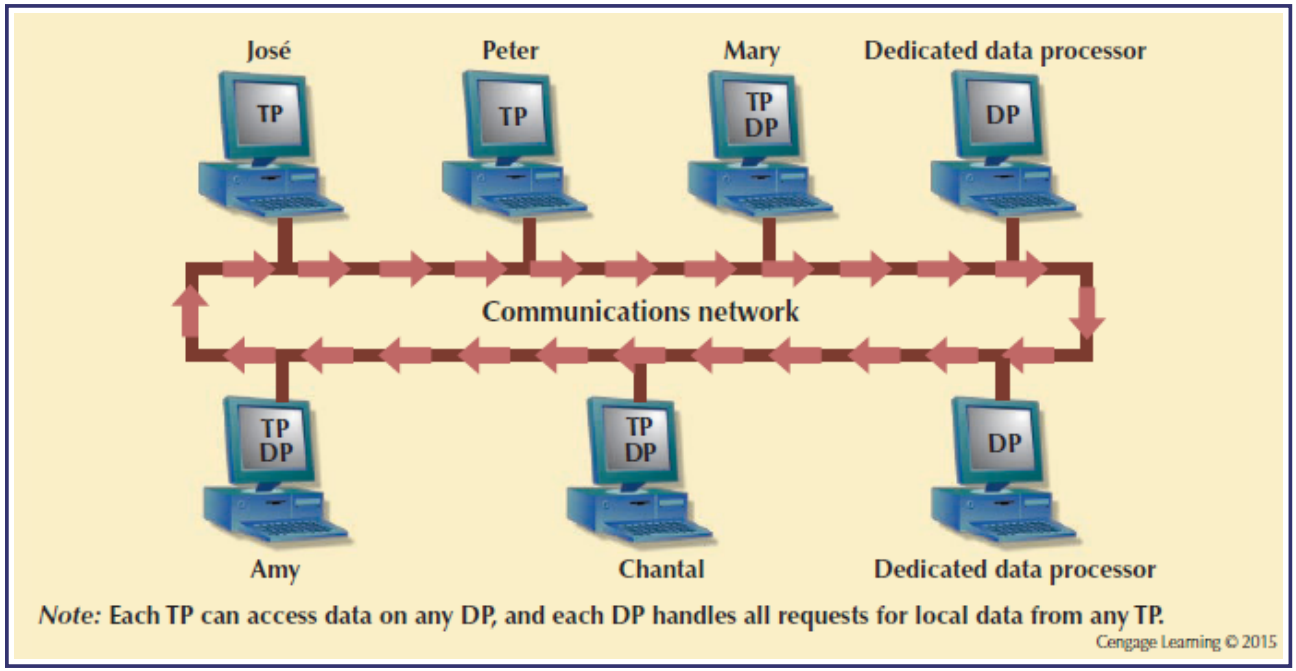
- Fully distributed database management system
  - Support multiple data processors and transaction processors at multiple sites
- Classification of DDBMS depending on the level of support for various types of databases
  - **Homogeneous**: Integrate multiple instances of same DBMS over a network
  - **Heterogeneous**: Integrate different types of DBMSs
  - **Fully heterogeneous**: Support different DBMSs, each supporting different data model

"The whole enchilada!".. Comes in three varieties.



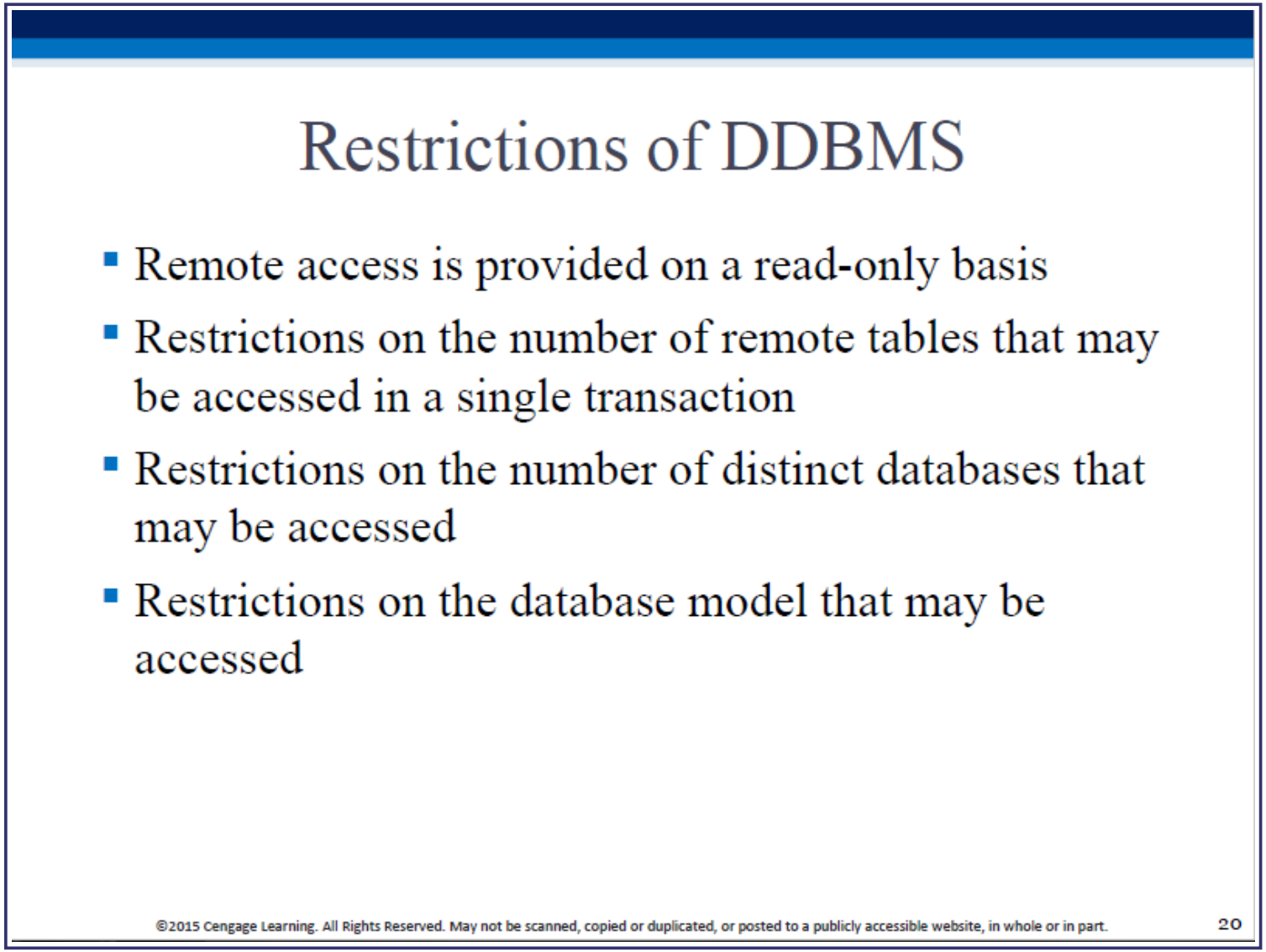
The above schematic is same as the one you saw earlier..

In a fully distributed database, the TPs (that request data) are distributed, as are the DPs (that serve data), like so [you saw this in an earlier slide]:



The DDBMS uses protocols to transport across its network, commands as well as data, from distributed DPs and TPs: it receives data requests from multiple TPs, collects/synchronizes data (needed by multiple TPs) from multiple DPs, and intelligently routes to multiple TPs, the data (collected from multiple DPs) they requested. In other words, since transactions need data, the DDBMS acts as a switch, shuttling and routing data, from multiple DPs, to multiple TPs.

DDBMS restrictions



DDBMs span the spectrum from homegenous to fully heterogenous, and tend to come with restrictions.

Local/distributed requests/transactions

Remote/localized requests and transactions:

Remote request

- Single SQL statement accesses data processed by a single remote database processor

Remote transaction

- Accesses data at single remote site composed of several requests

Distributed (not localized) requests and transactions:

Distributed request

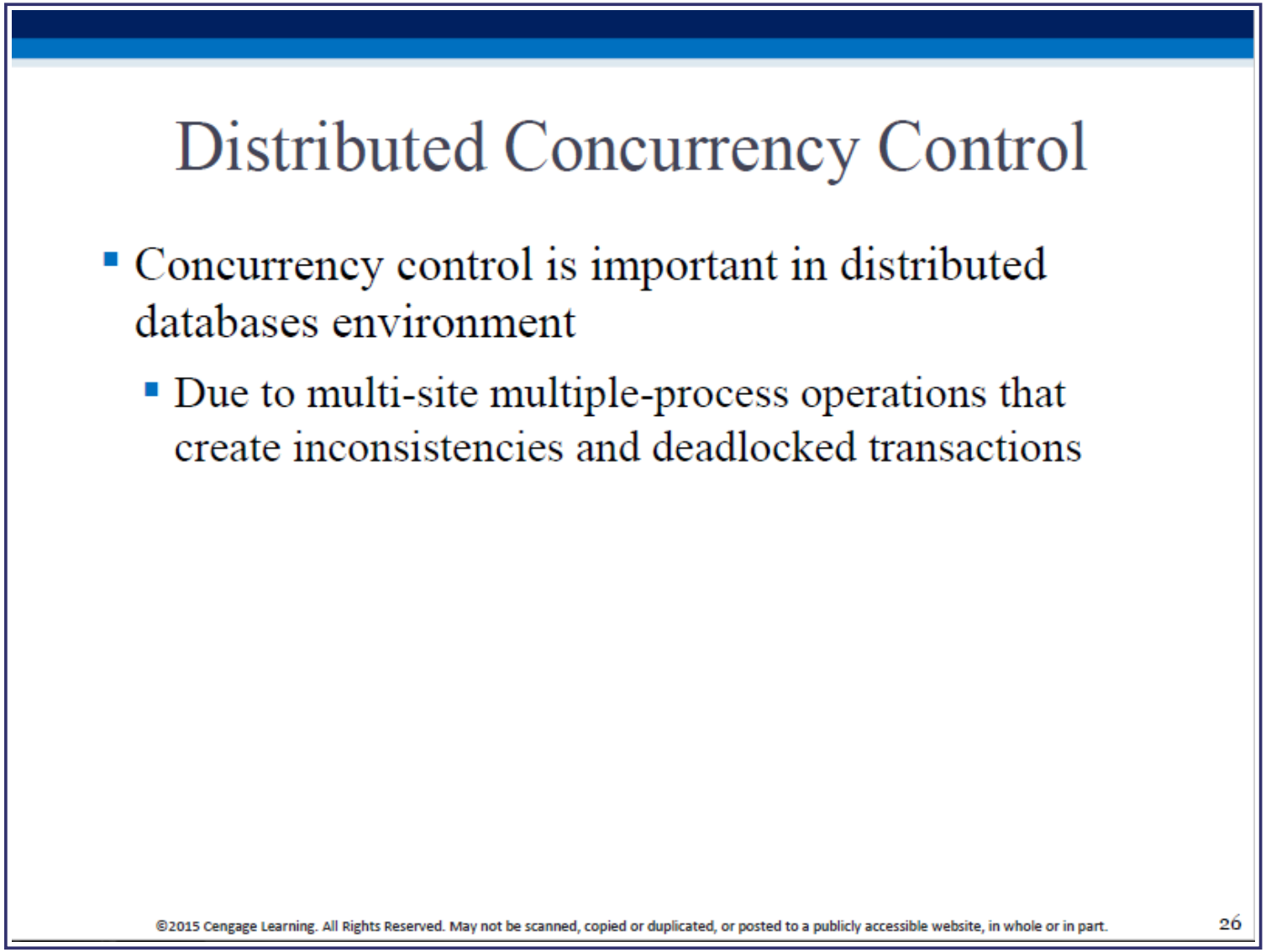
- Single SQL statement references data at several DP sites

Distributed transaction

- Requests data from several different remote sites on network

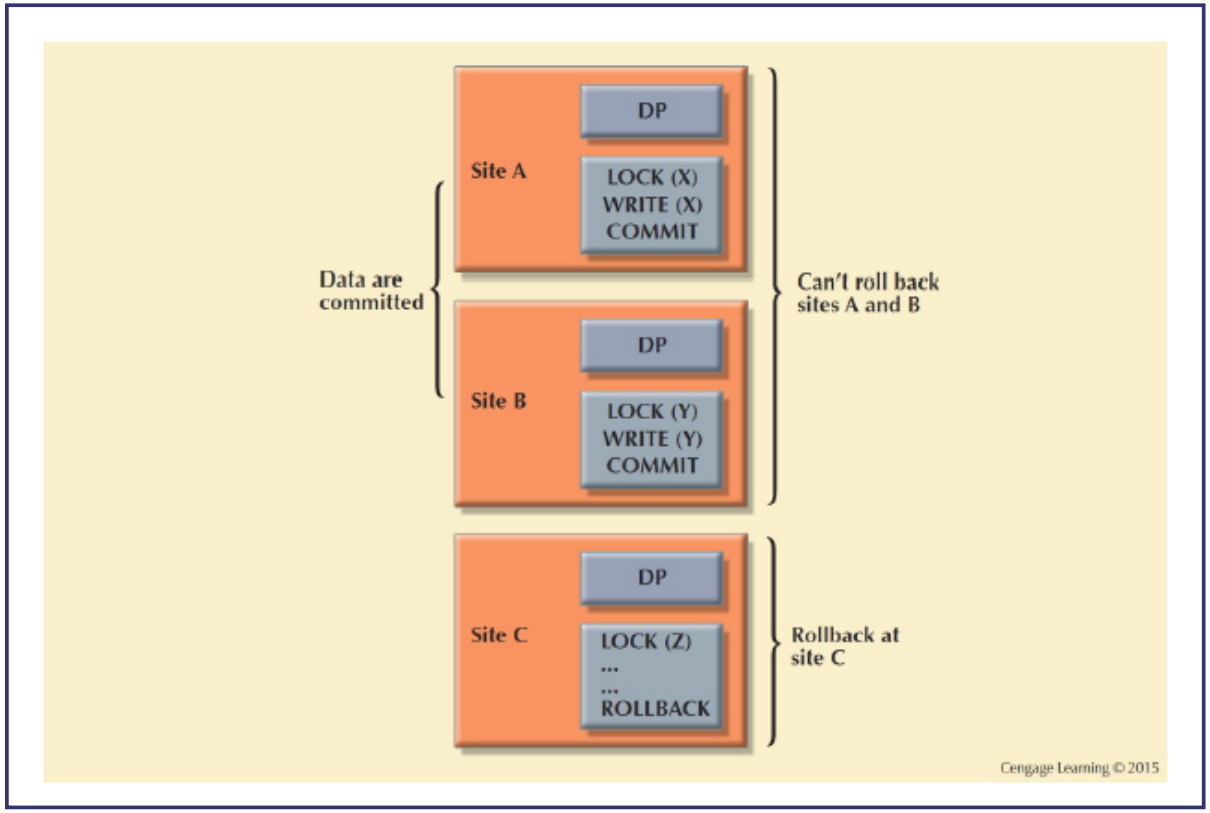
Distributed transactions are what need to be carefully executed so as to maintain distribution transparency - the transactions have to execute 'as if' they all ran on the same machine/location. This is achieved using '2PC' [explained in upcoming slides].

Distributed concurrency control



TP must ensure that all parts of a transaction (across sites) are completed, before doing a COMMIT.

Problem!



Can't COMMIT the entire transaction, can't ROLLBACK it either! Solution: 2PC.

Two-phase commit ("2PC") protocol

Two-Phase Commit Protocol (2PC)

- Guarantees if a portion of a transaction operation cannot be committed, all changes made at the other sites will be undone
  - To maintain a consistent database state
- Requires that each DP's transaction log entry be written before database fragment is updated
- **DO-UNDO-REDO protocol**: Roll transactions back and forward with the help of the system's transaction log entries

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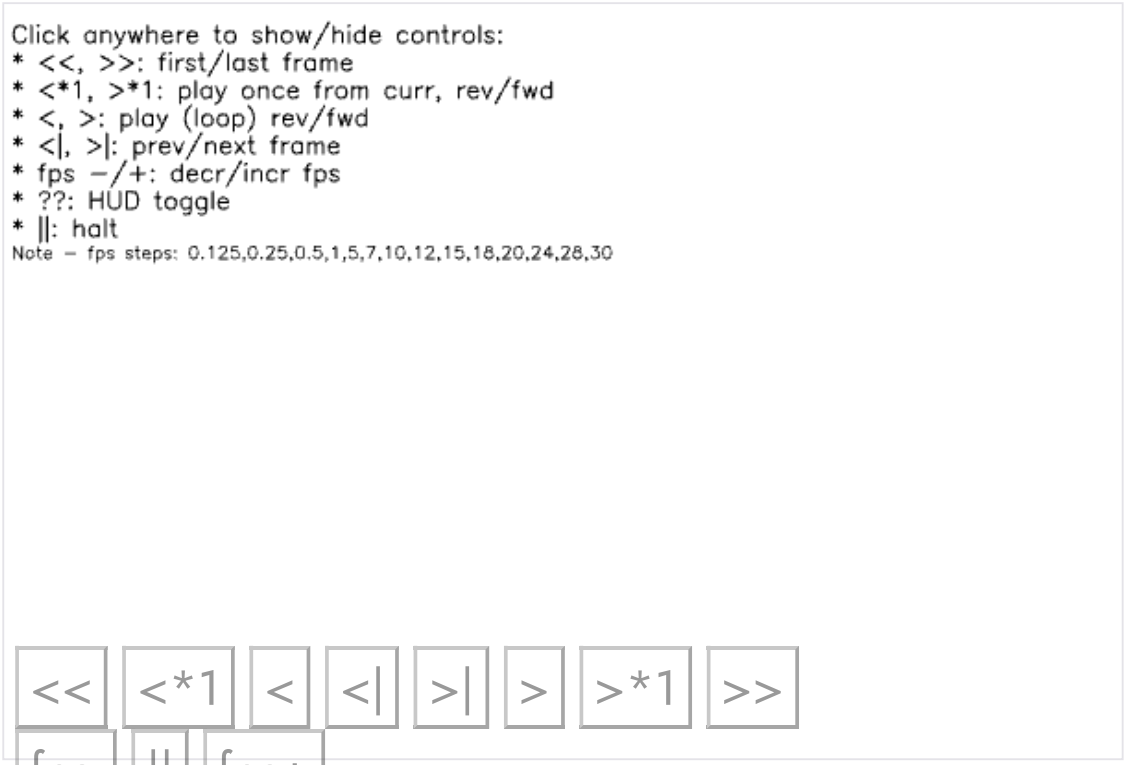
Two-Phase Commit Protocol (2PC)

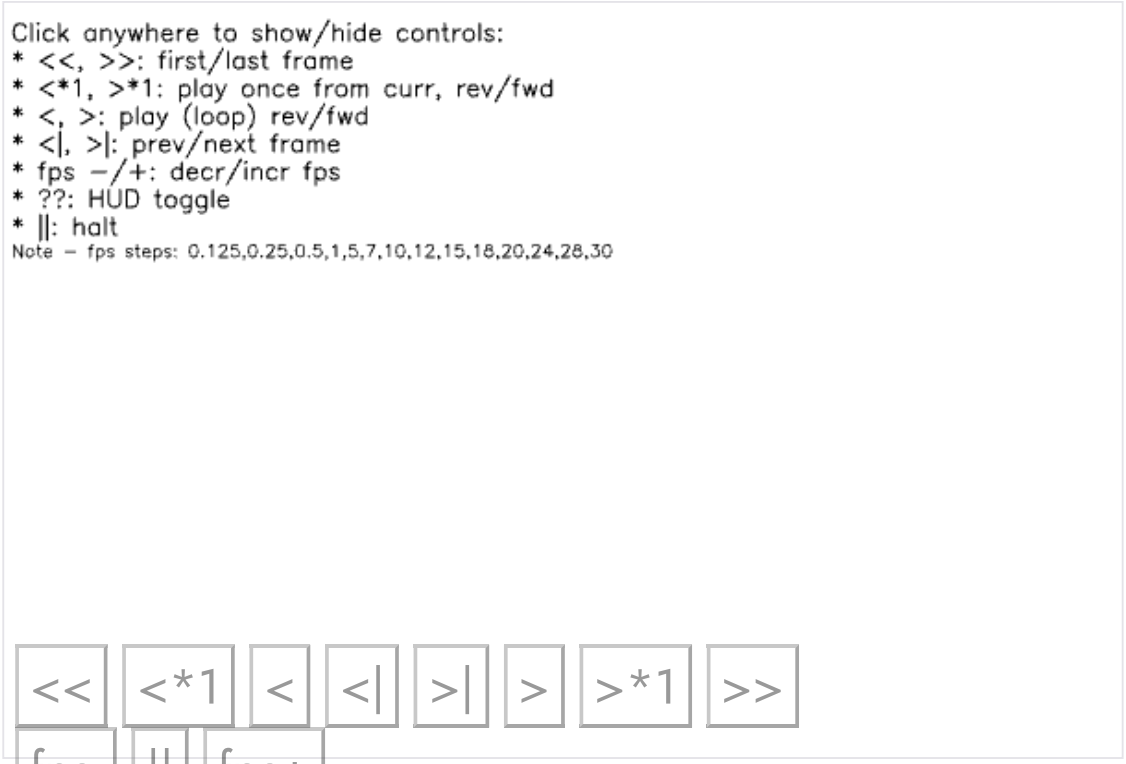
- **Write-ahead protocol**: Forces the log entry to be written to permanent storage before actual operation takes place
- Defines operations between **coordinator** and **subordinates**
- Phases of implementation
  - Preparation
  - The final COMMIT

2PC: steps

The following is the sequence of steps (phase 1, phase2) that are used to effect a complete distributed transaction (keep clicking on the >| button):



And here's how a transaction is aborted, when one of the participating nodes is unable to commit a sub-transaction:


Click anywhere to show/hide controls:
* <<, >>: first/last frame
* <*1, >*1: play once from curr, rev/fwd
* <, >: play (loop) rev/fwd
* <|, >|: prev/next frame
* fps −/+: decr/incr fps
* ??: HUD toggle
* ||: halt
Note − fps steps: 0.125,0.25,0.5,1,5,7,10,12,15,18,20,24,28,30
<<
<*1
<
<|
>|
>
>*1
>>
fps-
||
fps+

2PC: another description

In the two phase commit protocol, as the name implies, there are two phases:

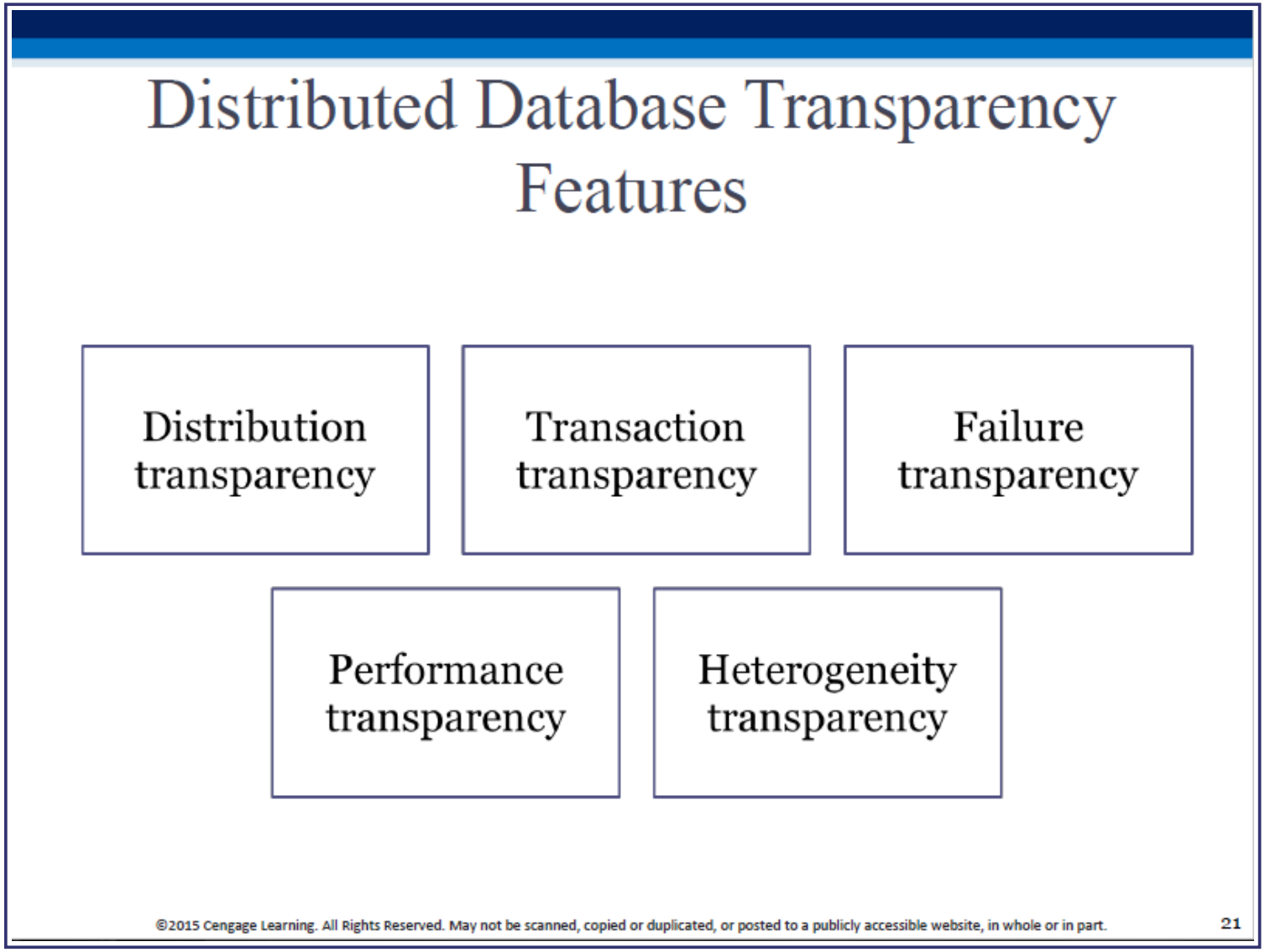
- phase 1: commit request phase, aka 'voting' phase: coordinator sends a 'commit or abort?' (aka 'query to commit' or 'prepare to commit') message to each participating transaction node; each node responds (votes), with a 'can commit' (aka 'ready') or 'need to abort' (aka 'abort') message
- phase 2: commit phase, aka 'completion' phase:
  - if in phase 1, all nodes responded with 'can commit', the coordinator sends a 'commit' phase to each node; each node commits, and sends an acknowledgment to the coordinator
  - or, if in phase 1, any node responded with 'need to abort', the coordinator sends an 'abort' message to each node; each node aborts, and sends an acknowledgment to the coordinator

The devil's in the details - all sorts of variations/refinements exist in implementations, but the above is the overall (simple, robust) idea.

It's an all-or-nothing scheme - either all nodes of a distributed transaction locally commit (in which case the overall transaction is successful), or all of them locally abort so that the DB is not left in an inconsistent state unlike in the 'Problem!' slide (in which case the overall transaction fails and needs to be redone).

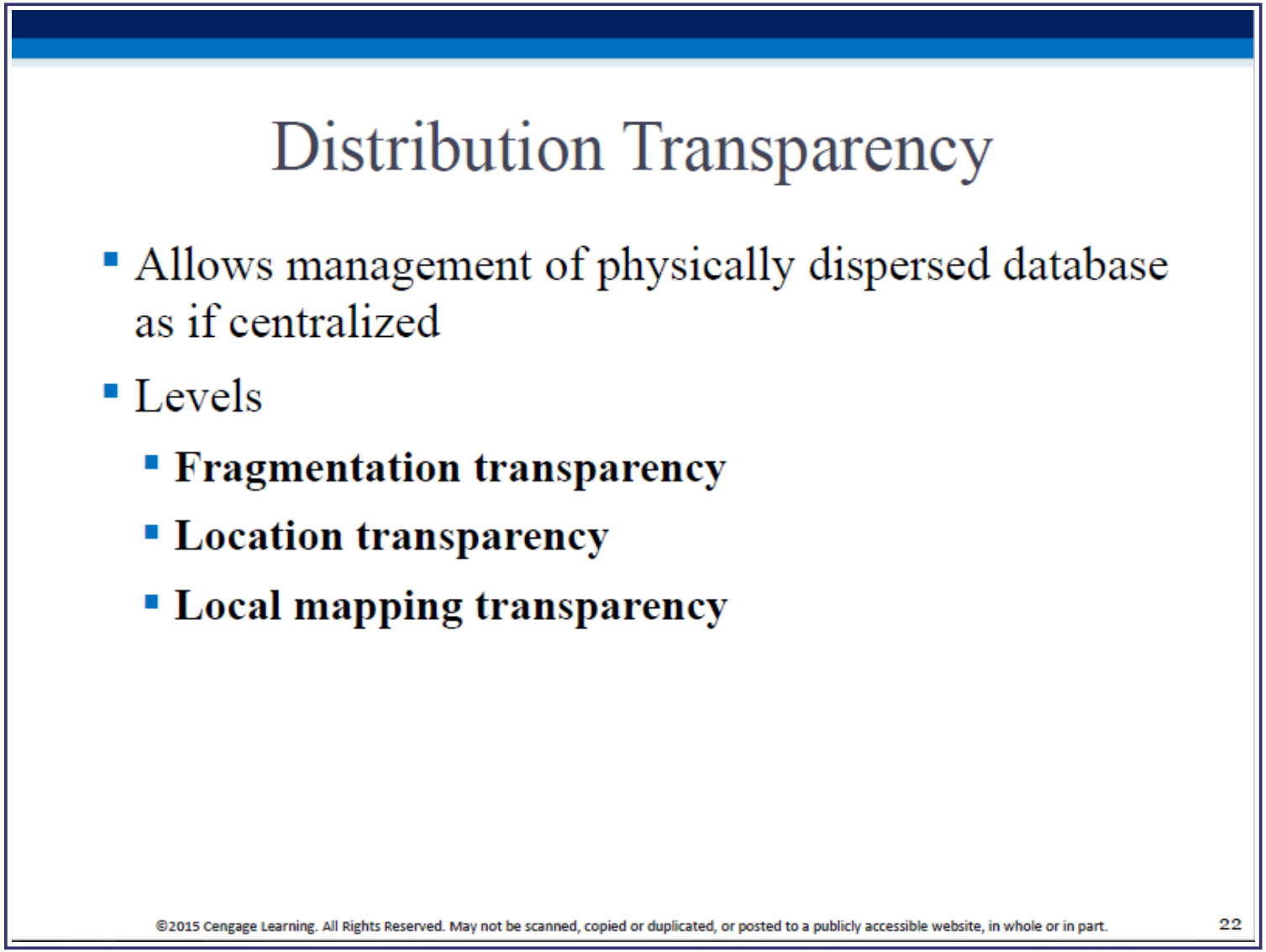
FYI, this is yet another description :)

"What distribution? We have NO distribution!"



DDBMSs are designed to HIDE distribution specifics - this feature is called 'transparency', and can be classified into different kinds.

Distribution transparency



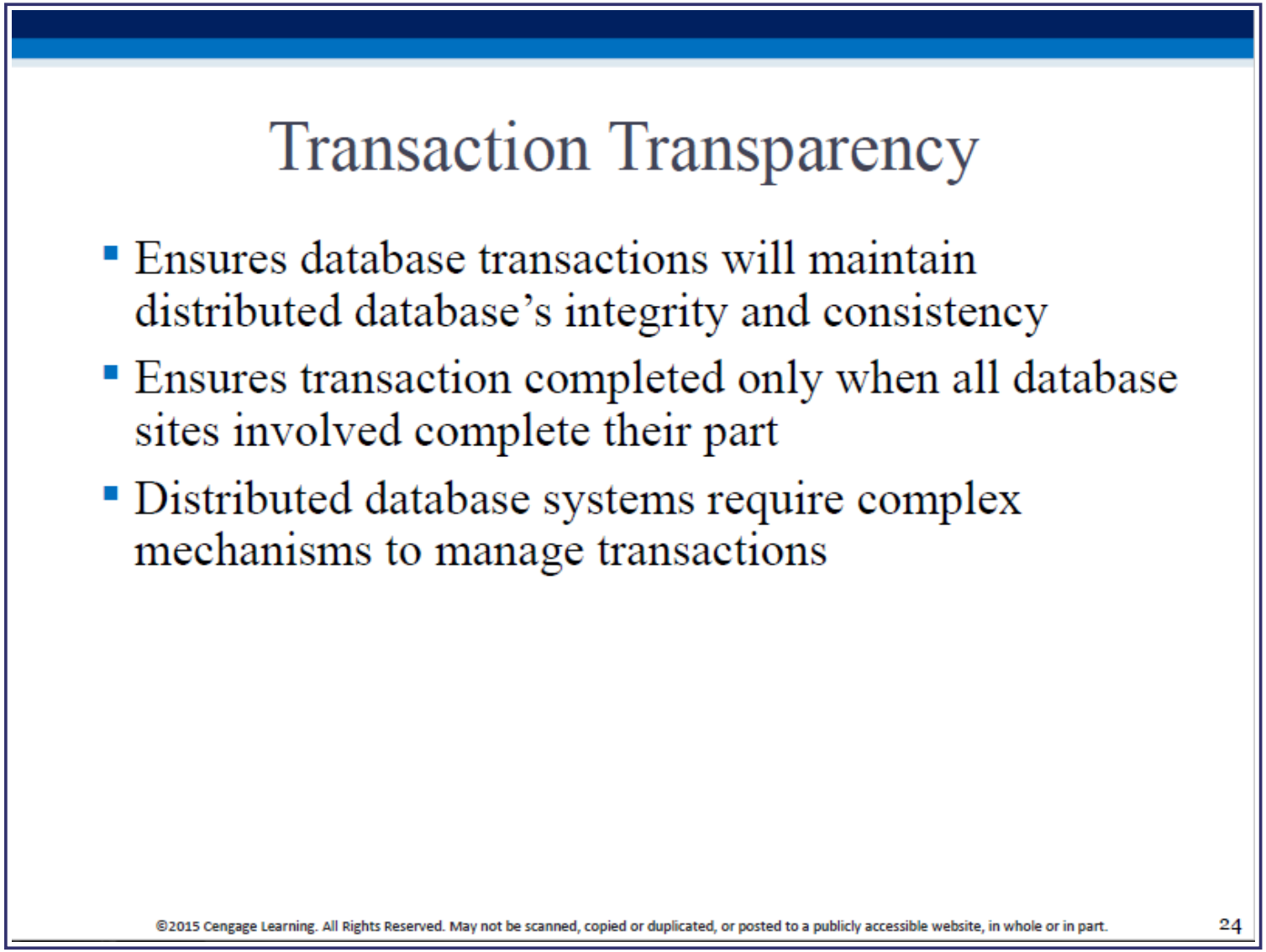
Fragmentation transparency: end user does not know that the data is fragmented.

Location transparency: end user does not know where fragments are located.

Location mapping transparency: end user does not know how fragments are mapped.

Distrib. transparency is supported via a distributed data dictionary (DDD) [aka DDC], which contains the distributed global schema which local TPs use to translate user requests for processing by DPs.

Transaction transparency



Performance transparency, failure transparency

Performance and Failure Transparency

- **Performance transparency**: Allows a DDBMS to perform as if it were a centralized database
- **Failure transparency**: Ensures the system will operate in case of network failure
- Considerations for resolving requests in a distributed data environment
  - Data distribution
  - Data replication
    - **Replica transparency**: DDBMS's ability to hide multiple copies of data from the user

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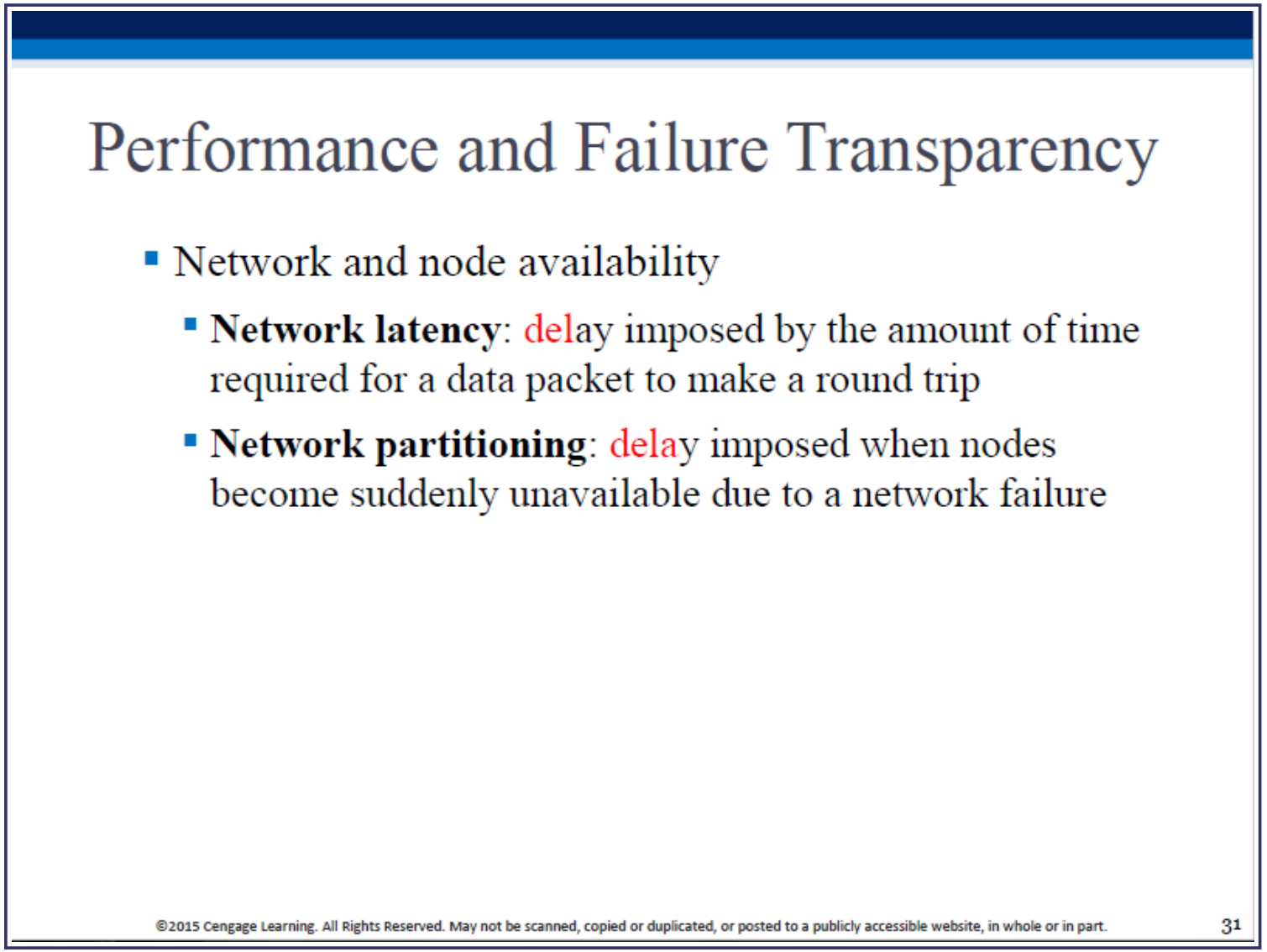
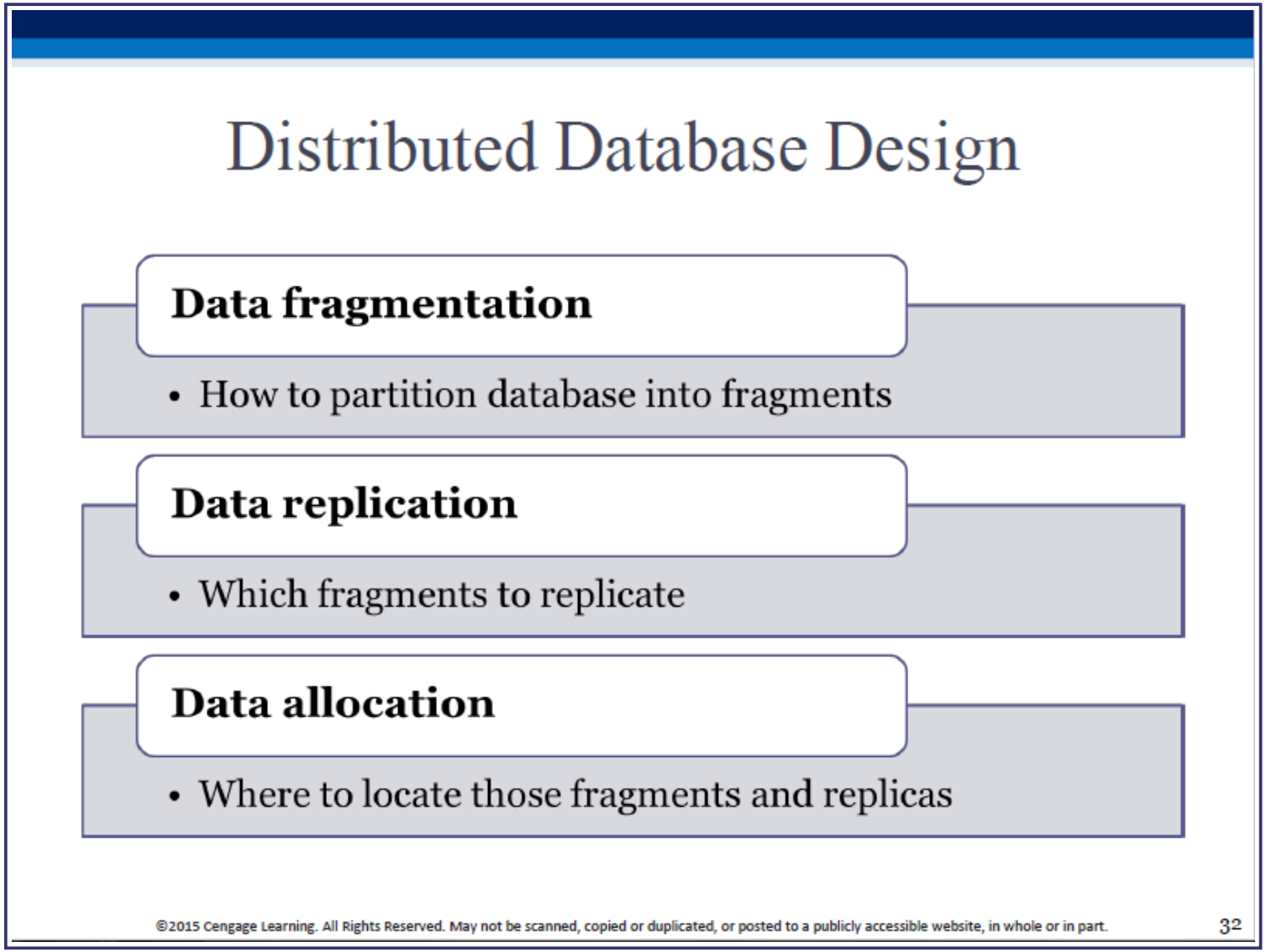


We also need to take into account, network delay and network failure ("partitioning") when planning for or evaluating transparency.

Distributed DB design



Partition (divide), replicate (copy)? Where to store the partitions/copies?

Fragmentation (partitioning)

Data Fragmentation

- Breaks single object into many segments
  - Information is stored in distributed data catalog (DDC)
- Strategies
  - **Horizontal fragmentation**: Division of a relation into subsets (fragments) of tuples (rows)
  - **Vertical fragmentation**: Division of a relation into attribute (column) subsets
  - **Mixed fragmentation**: Combination of horizontal and vertical strategies

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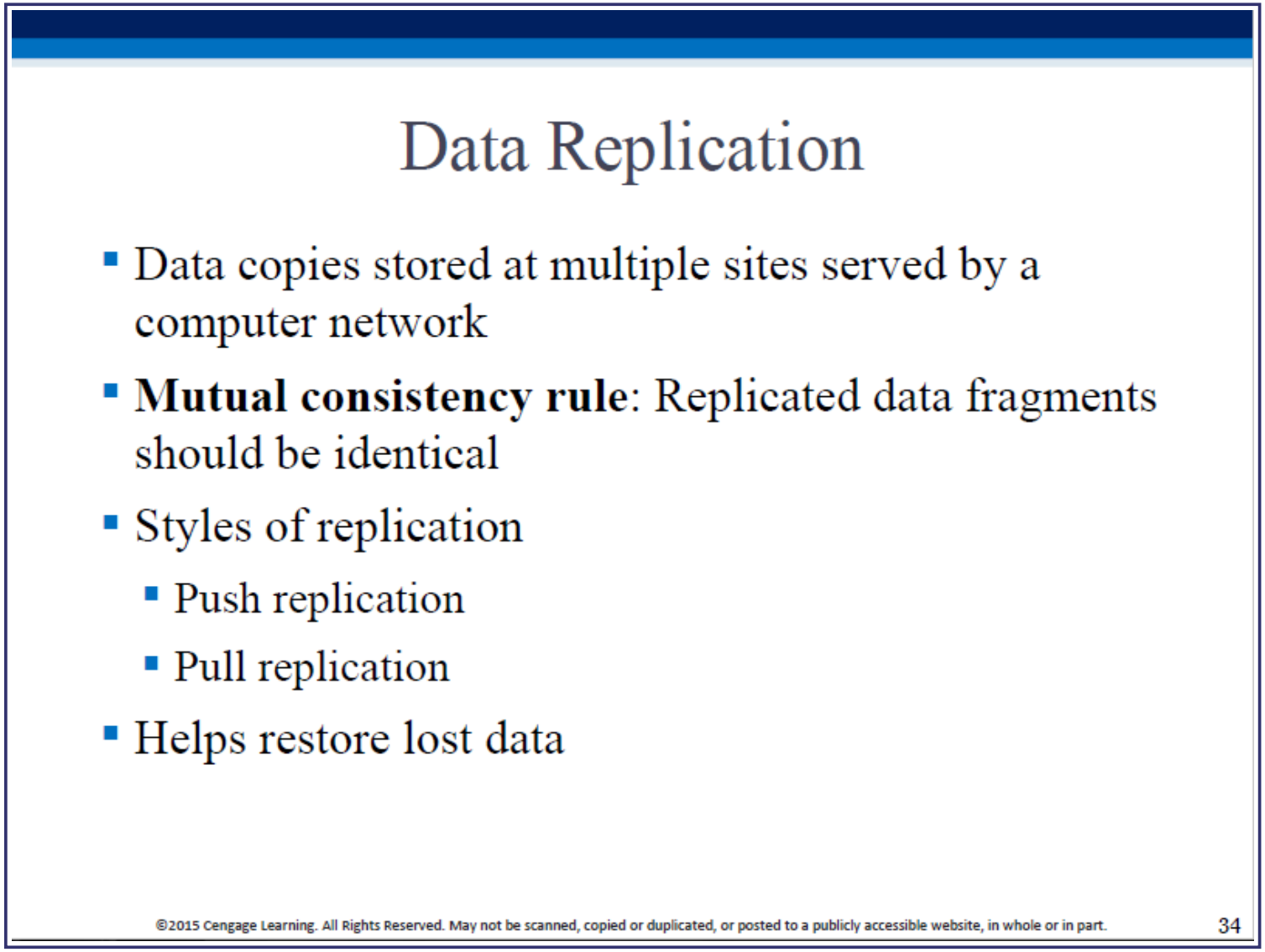
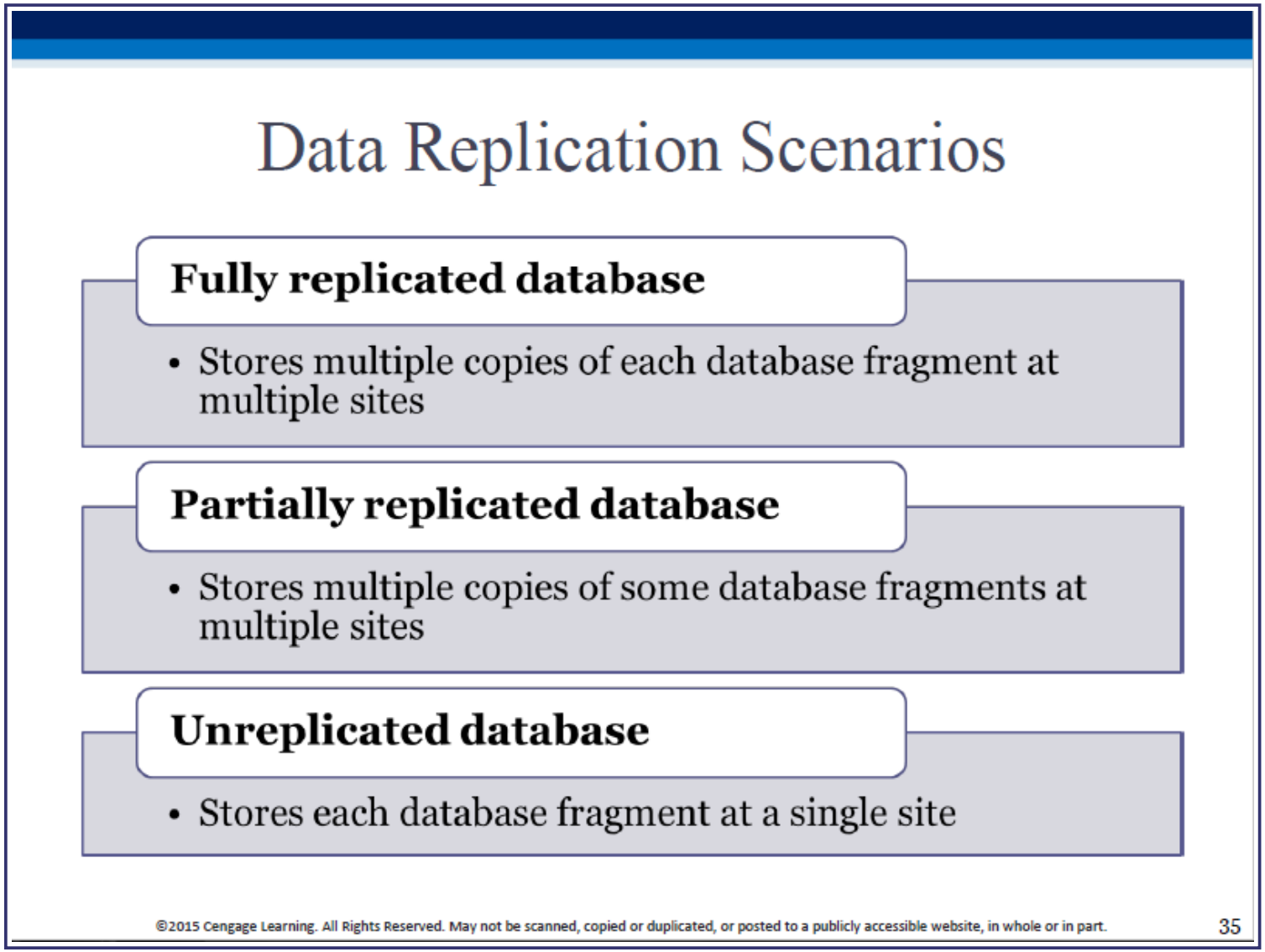
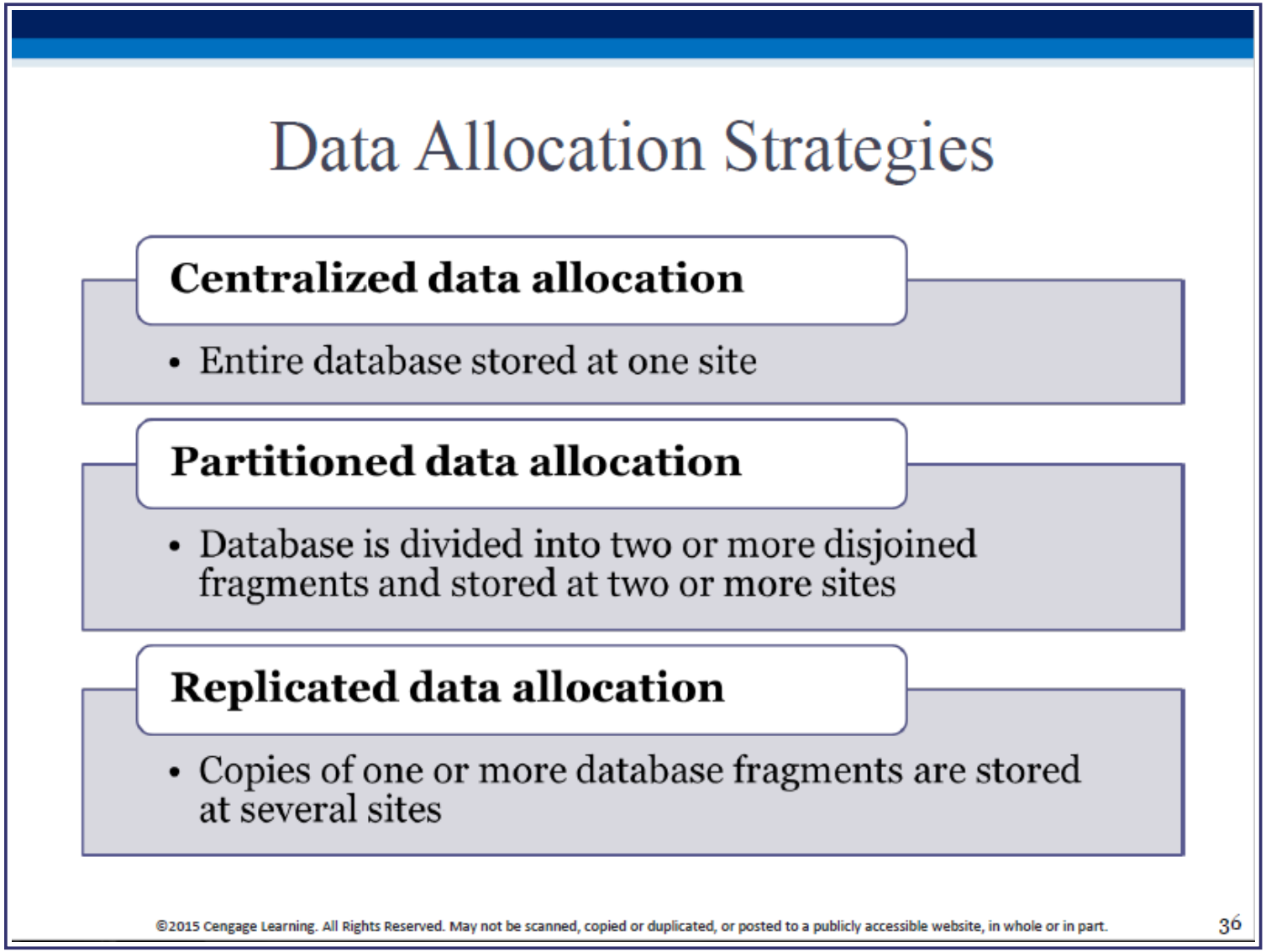
Replication



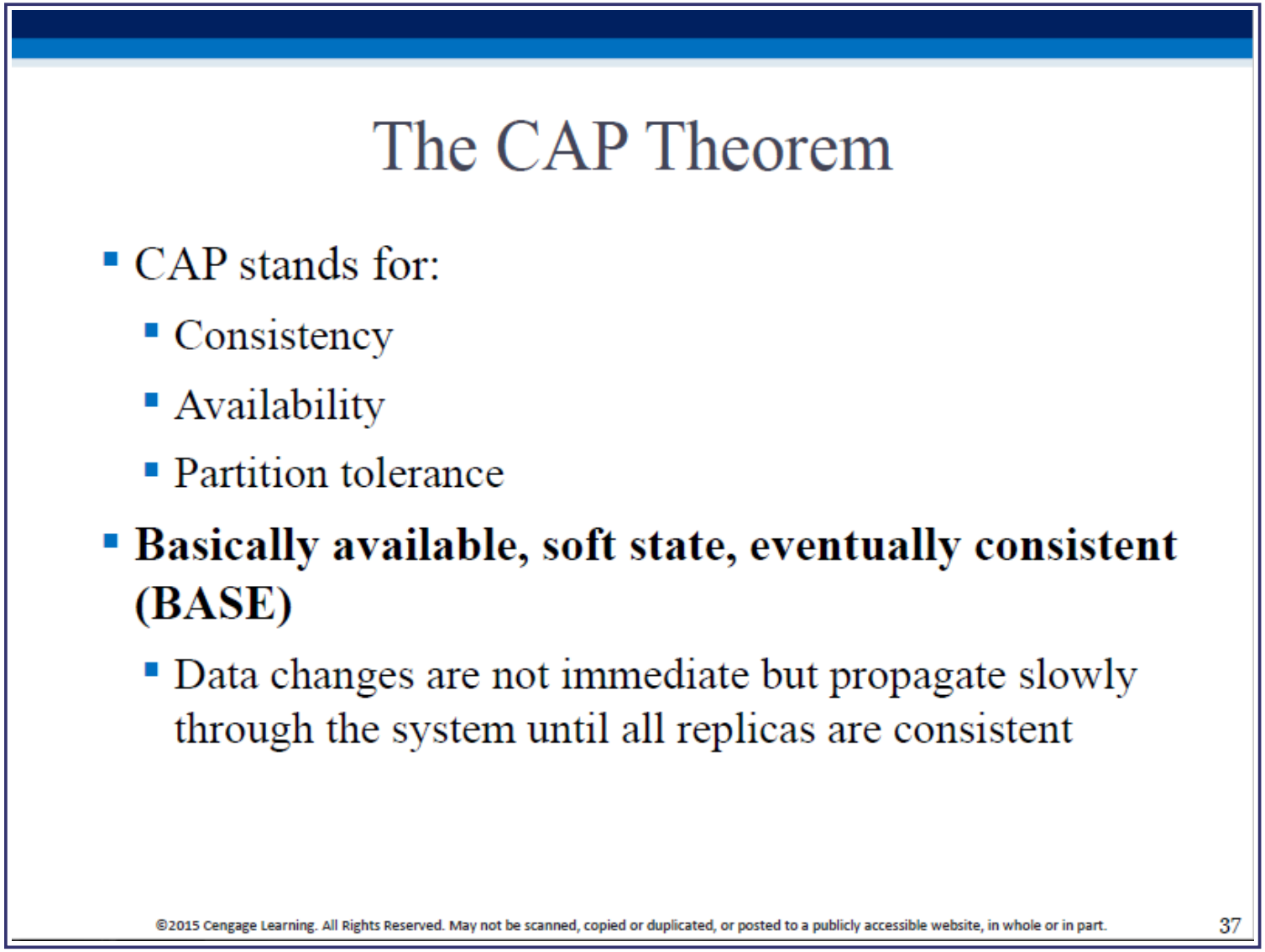


You can read more about replication, here.

Storage of fragments/replicas



The CAP 'theorem' [2 out of 3; 1 out of 2]



Consistency: always correct data.

Availability: requests are always filled.

Partition ("outage") tolerance: continue to operate even if (some/most) nodes fail.

The CAP theorem 'used to say' that in a networked (distributed) DB system, at most 2 out of 3 of the above are achievable [PC, CA, or PA]. But CA means low P, that means that we can't even operate, which makes CA a moot point! In other words, **CA doesn't exist**, ie. a low P is not an option! So now we think of it differently: in the event of a network partition (P has occurred), only one of availability or consistency is achievable. You can read more here.

In the 'ACID' (Atomicity, Consistency, Isolation, Durability) world of older relational DBs, the CAP Theorem was a reminder that it is usually difficult to achieve C,A,P all at once, and that consistency is more important than availability.

In today's 'BASE' (Basically Available, Soft_state, Eventually_consistent) model of non-relational (eg. NoSQL) DBs, we prefer to sacrifice consistency in favor of availability.

DBMS TYPE	CONSISTENCY	AVAILABILITY	PARTITION TOLERANCE	TRANSACTION MODEL	TRADE-OFF
Centralized DBMS	High	High	N/A	ACID	No distributed data processing
Relational DDBMS	High	Relaxed	High	ACID	
(2PC)	Sacrifices availability to ensure consistency and isolation				
NoSQL DDBMS	Relaxed	High	High	BASE	Sacrifices consistency to ensure availability

Date's '12 commandments' for distributed DBMSs

RULE NUMBER	RULE NAME	RULE EXPLANATION
1	*Local-site independence*	Each local site can act as an independent, autonomous, centralized DBMS. Each site is responsible for security, concurrency control, backup, and recovery.
2	*Central-site independence*	No site in the network relies on a central site or any other site. All sites have the same capabilities.
3	*Failure independence*	The system is not affected by node failures. The system is in continuous operation even in the case of a node failure or an expansion of the network.
4	*Location transparency*	The user does not need to know the location of data to retrieve those data.
5	*Fragmentation transparency*	Data fragmentation is transparent to the user, who sees only one logical database. The user does not need to know the name of the database fragments to retrieve them.
6	*Replication transparency*	The user sees only one logical database. The DDBMS transparently selects the database fragment to access. To the user, the DDBMS manages all fragments transparently.
7	*Distributed query processing*	A distributed query may be executed at several different DP sites. Query optimization is performed transparently by the DDBMS.
8	*Distributed transaction processing*	A transaction may update data at several different sites, and the transaction is executed transparently.
9	*Hardware independence*	The system must run on any hardware platform.
10	*Operating system independence*	The system must run on any operating system platform.
11	*Network independence*	The system must run on any network platform.
12	*Database independence*	The system must support any vendor's database product.

Think of these more as checklist items, rather than commandments.