Prof. Dr.-Ing. Stefan Deßloch
AG Heterogene Informationssysteme
Geb. 36, Raum 329
Tel. 0631/205 3275
dessloch@informatik.uni-kl.de

TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

Chapter 2
Distributed Information Systems Architecture

Chapter Outline

- Distributed transactions (quick refresh)
- Layers of an information system
  - presentation
  - application logic
  - resource management
- Design strategies
  - top-down, bottom-up
- Architectures
  - 1-tier, 2-tier, 3-tier, n-tier
- Distribution alternatives
- Communication
  - synchronous, asynchronous

"ACID" Transactions

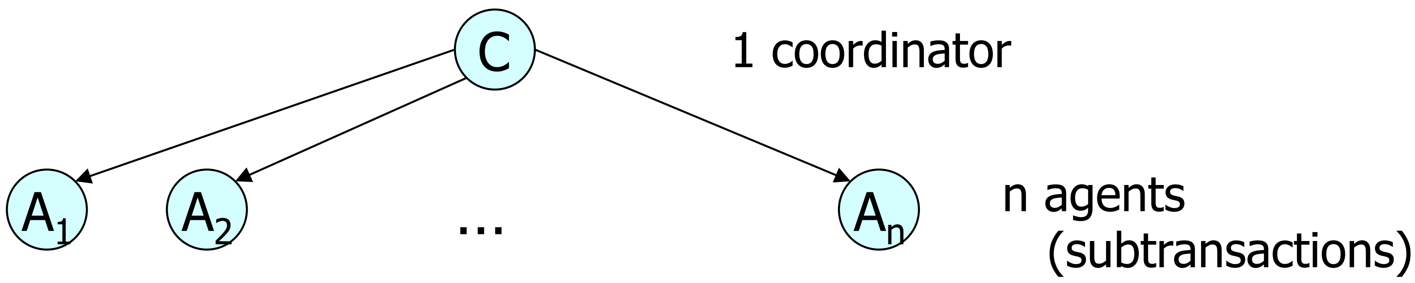
- **A**tomicity
  - TA is an atomic processing unit
  - "all-or-nothing" guarantee
- **C**onsistency
  - completed TA results in consistent DB state
  - intermediate states may be inconsistent
  - final state has to satisfy DB integrity constraints
- **I**solation
  - concurrent TAs must not influence each other
- **D**urability
  - DB changes of a successfully completed TA are guaranteed to "survive"
  - system crash must not cause loss of changes
  - changes of completed TA can only be undone by executing another TA (compensating TA)

Communication between TA Program and DBS

Application program	**DBS**
BOT	Guarantee that changes can be rolled back
.	
.	
Op_i	Execute DML operation (check immediate constraints)
.	
.	
EOT	(check deferred constraints)
phase 1	Guarantee recoverability of all changes
2PC	
phase 2	Release resources (locks)
	Acknowledge TA success

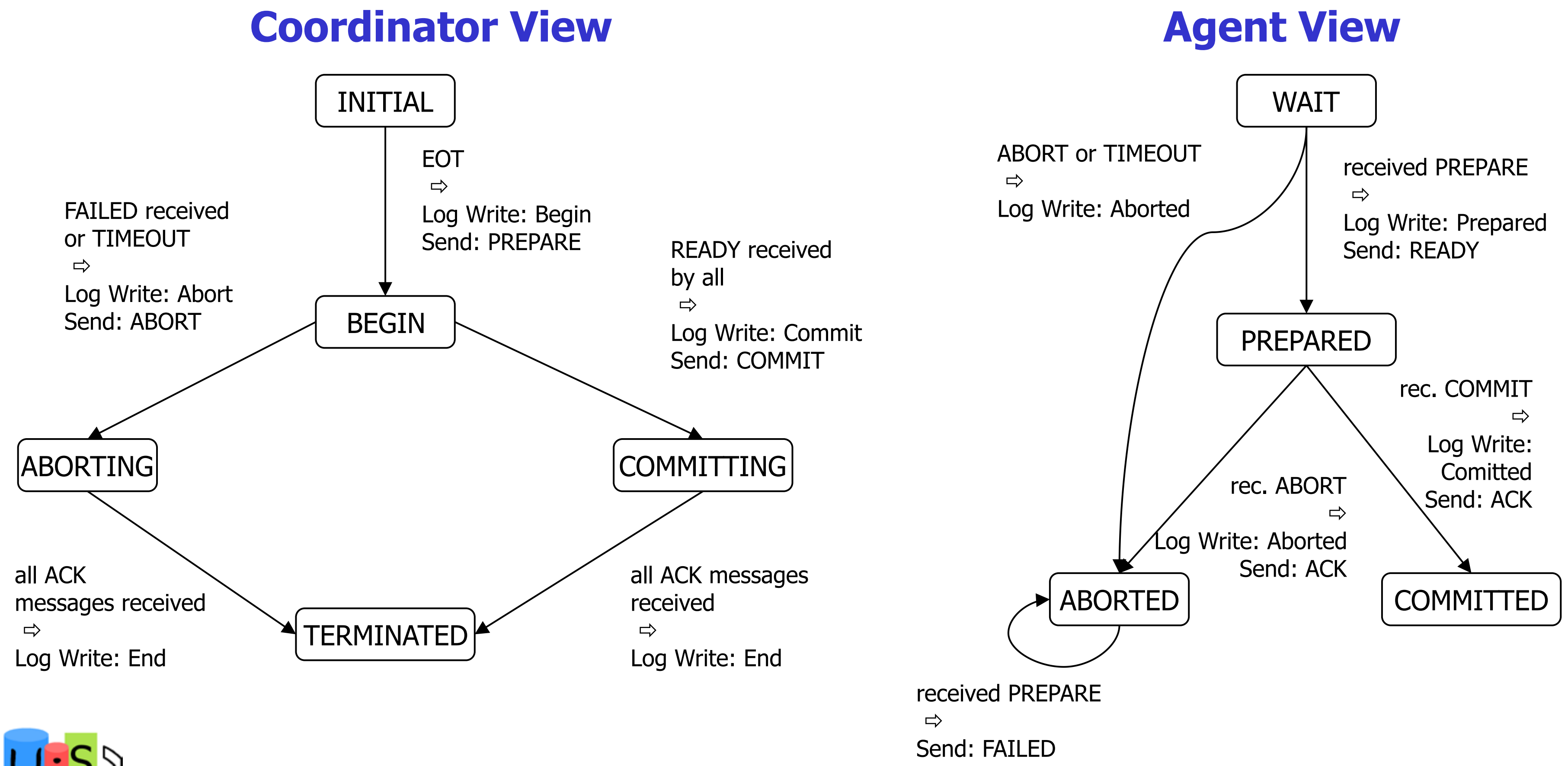
Distributed Transactions

- Distributed Information System
  - consists of (possibly autonomous) subsystems jointly working in a coordinated manner
  - may involve multiple resource managers (e.g., DBS)
- Require global (multi-phase) commit protocol to guarantee atomicity of global TA
  - handled by a coordinator
  - involving multiple agents (participants)
- requirements for commit protocol
  - minimal effort (#messages, #log entries)
  - minimal response delay (parallelism)
  - robustness against failure
- expected failure
  - partial failure (connection loss, ...)
  - transaction failure
  - system failure (crash)
  - hardware failure
- failure detection (e.g., using time-out)



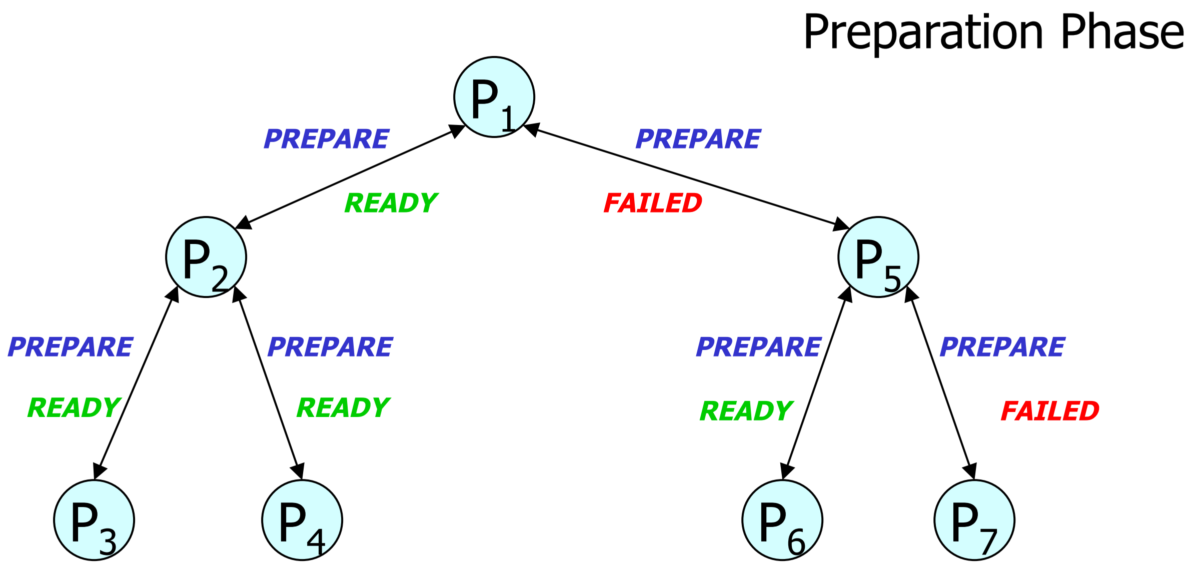
Two-phase Commit

- Prepare-Phase, Commit/Abort-Phase
- Requires sequence of state transitions, to be safely stored in the transaction log



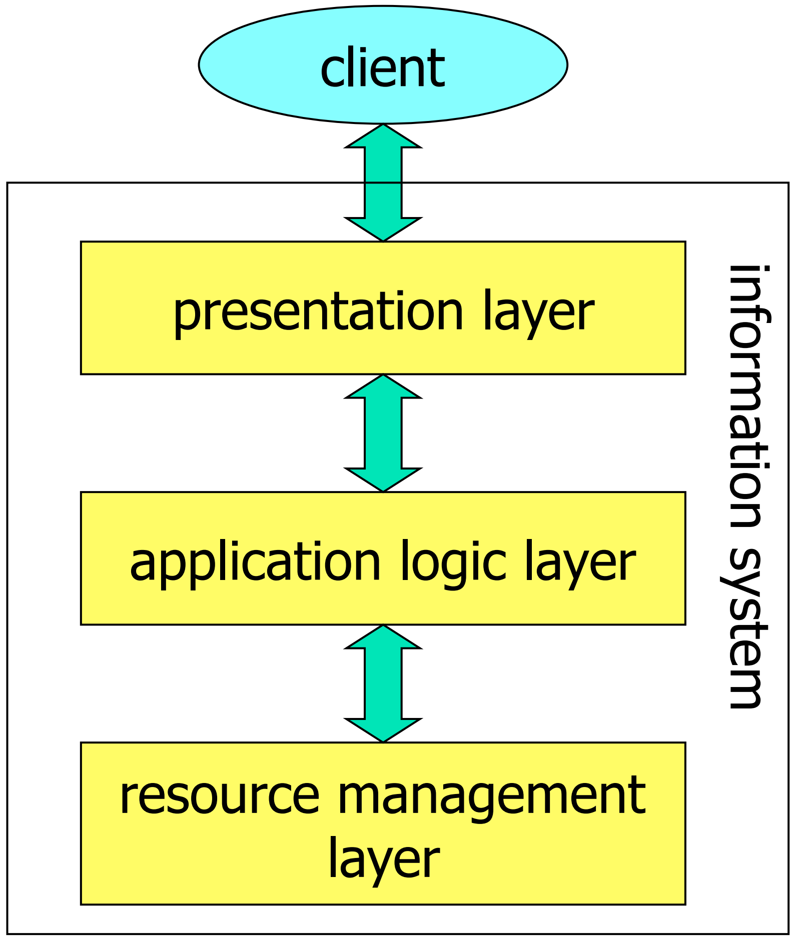
Hierarchical 2PC

- Execution of transaction may form a process tree
  - initiator at the root
  - edges represent process links for request/response
- Hierarchical 2PC, with each node acting as a
  - agent/participant for its caller
  - coordinator for its subtree



Layers of an Information System

- Separation of functionality into three **conceptual** layers
  - presentation
    - interacts with client
      - present information
      - accept requests
    - graphical user interface, or module that formats/transforms data, or …
  - application logic
    - programs that implement the services offered by the IS
      - often retrieves/modifies data
  - resource management
    - manages the data sources of the IS
      - DBMSs
      - file system
      - any "external" system
- In an IS implementation, these layers might not be clearly distinguishable



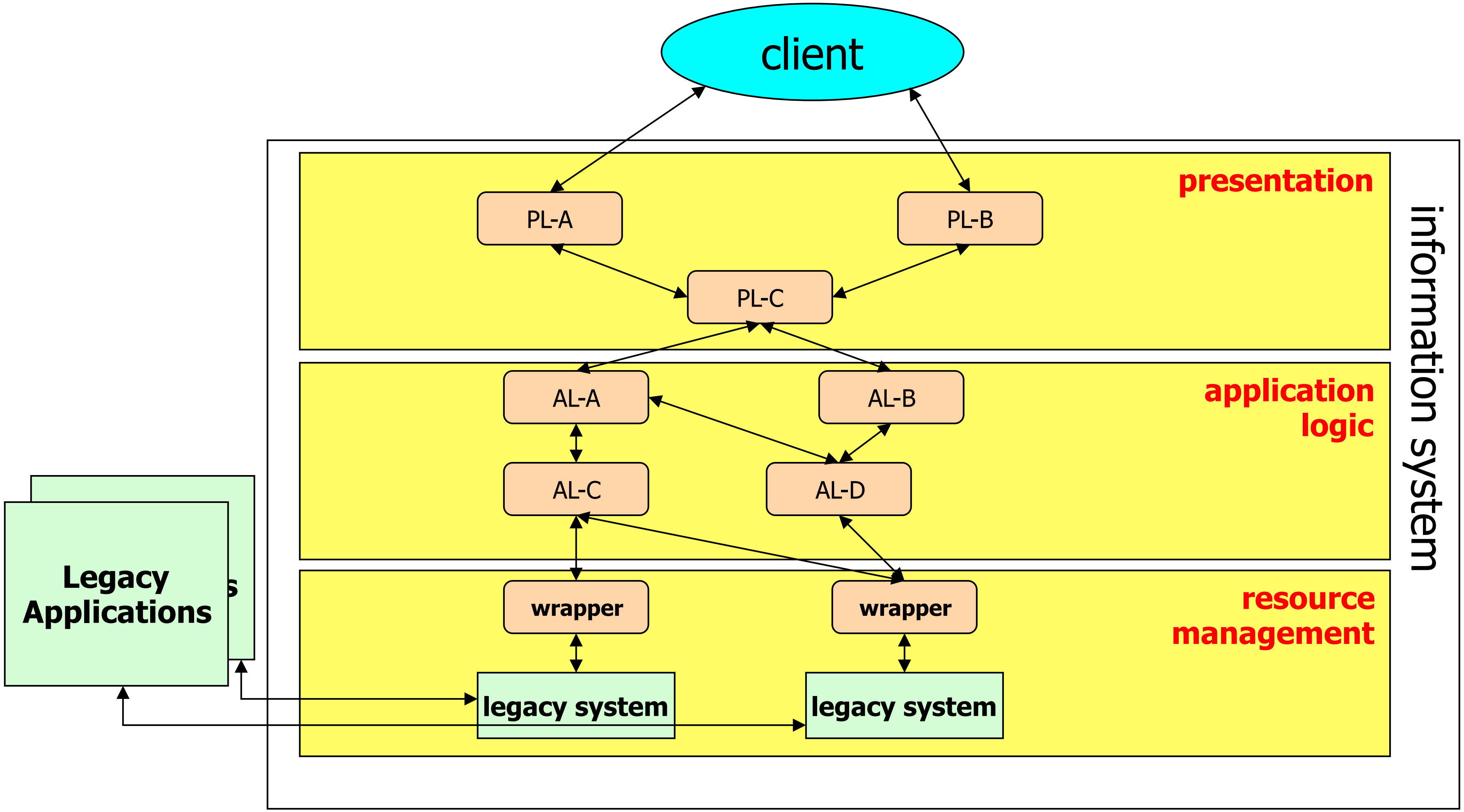
Top-Down Information System Design

- Steps
  1) define access channels and client platforms
  2) define presentation formats and protocols
  3) define functionality (application logic) necessary to deliver the content and formats
  4) define the data sources and data organization needed
- Design involves specification of system distribution across different computing nodes
  - distribution possible at every layer
- Homogenous environment, tightly-coupled components
- **Pro**: focus on high-level goals, addresses both functional and non-functional requirements
- **Con**: can only be applied if IS is developed from scratch

Bottom-up Information System Design

- Steps
  1) define access channels and client platforms
  2) examine existing resources and their functionality (RM layer)
  3) wrap existing resources, integrate them into consistent interface (AL layer)
  4) adapt output of AL for client (P layer)
- Design focuses on integration/reuse of existing (legacy) systems/applications
  - functionality of components is already (pre-)defined
    - modification or re-implementation is often not a choice
  - driven by characteristics of lower layers
    - start with high-level goals, then determine how it can be achieved using existing components
  - often starts with thorough analysis of existing applications and systems to determine which high-level objectives can be achieved
  - results in loosely-coupled systems
    - components can mostly be used stand-alone
    - underlying systems often remain autonomous
- Not an advantage, but a necessity

Bottom-Up Design Example



Information Systems Architecture

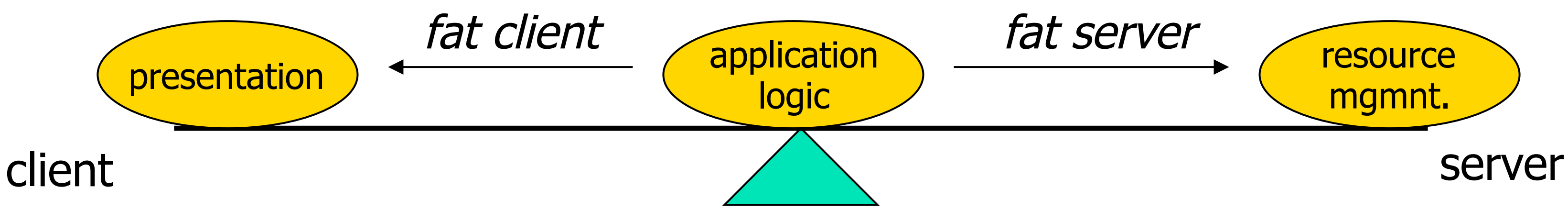
- Layers define a logical separation of functionality
- Implementing an IS
  - decide how to combine/distribute the layers into so-called tiers
- Tier
  - modularizes the IS architecture
  - may implement a (part of a) single layer, or multiple layers
  - provides well-defined interfaces for accessing its functionality
  - tier ≠ node
- Going from N to N+1 tiers in general
  - adds flexibility, functionality, distribution and scalability options
  - introduces performance, complexity, management, tuning issues

1-Tier Architecture

- All layers are combined in a single tier
- Predominant on mainframe-based computer architectures
  - client is usually a "dumb terminal"
  - focus on efficient utilization of CPU, system resources
- "Monolithic" system
  - no entry points (APIs) from outside, other than the channel to the dumb terminals
  - have to be treated as black boxes
  - integration requires "screen scraping"
    - program that simulates user, parses the "screens" produced by the system
  - the prototype of a legacy system
- Advantages
  - optimizes performance by merging the layers as necessary
  - client development, deployment, maintenance is not an issue
- Disadvantages
  - difficult and expensive to maintain
    - further increased by lack of documentation and qualified programmers

2-Tier Architecture

- Pushed by emergence of PC, workstations (replacing dumb terminals)
  - presentation layer is moved to the PC
    - exploit the processing power of PC
      - free up resources for application logic/resource management layers
    - possibility to tailor presentation layer for different purposes
      - e.g., end-user presentation vs. administrator presentation modules
  - typically realized as client/server system
    - one (popular) approach: client corresponds to presentation layer, server includes the application logic and resource management layers
    - another approach (more traditional C/S): client includes presentation and application logic layer, server provides resource management services
    - where does the client end and the server begin?
      - thin client/fat server vs. fat client/thin server

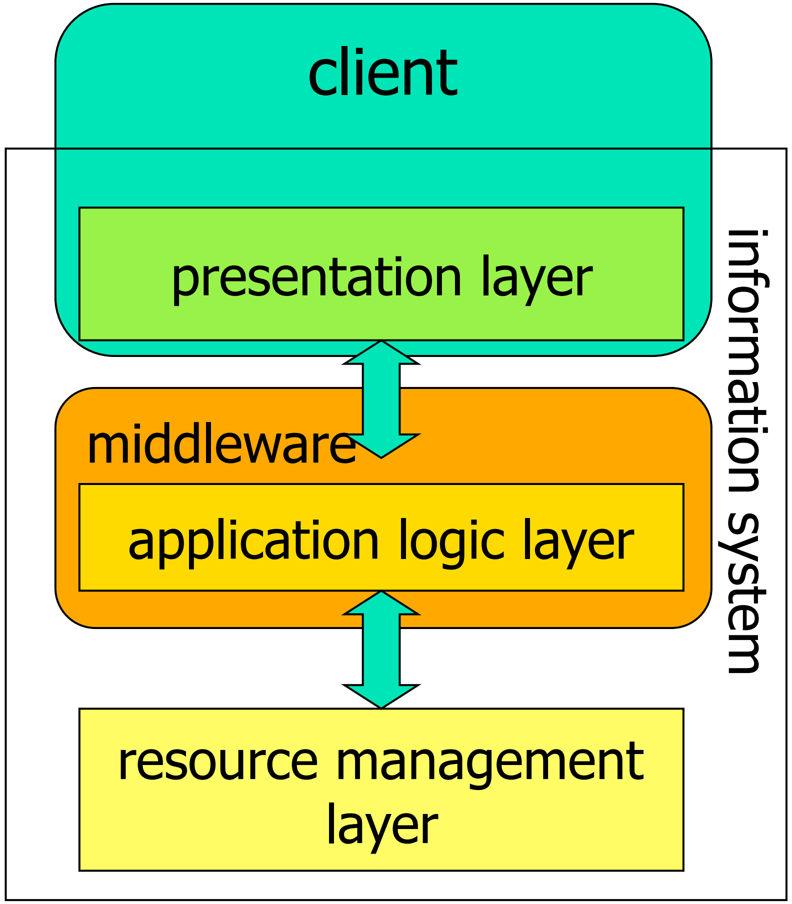


Properties of 2-Tier Architecture

- Pro
  - emphasis on "services" provided by server, requested/consumed by client
  - definition of application programming interfaces (APIs) as published server interfaces
    - portability, stability
    - multiple types of clients can utilize the same server API
  - server can support multiple clients at the same time
  - sufficient scalability for departmental applications
- Con
  - scalability is often limited (esp. for thin clients)
    - requires to move to very powerful server machines
  - especially fat clients require increased software maintenance/deployment on client side
  - client is often turned into an integration engine interacting with multiple types of servers
    - extra application layer appears in thin clients

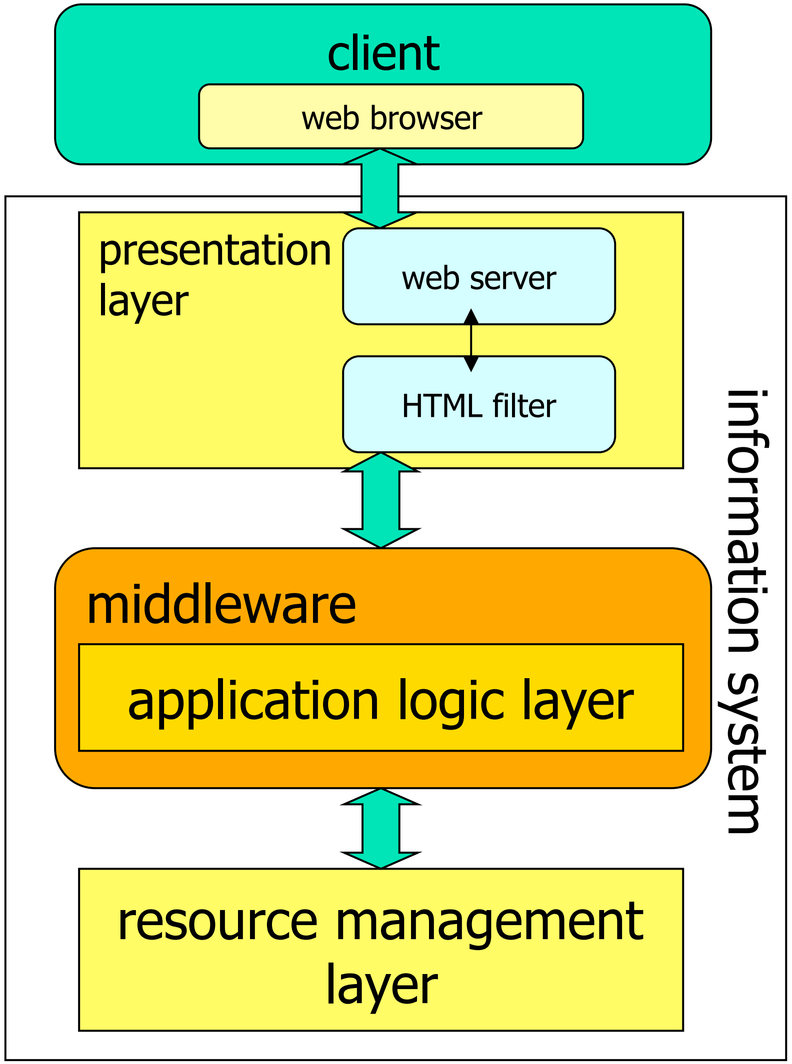
3-Tier Architecture

- Usually based on a clear separation between the three layers
  - client tier implements presentation layer
  - middle tier realizes application logic
    - employs middleware
  - resource management layer composed of a (set of) servers (e.g., DBS)
- Addresses scalability
  - application layer can be distributed across nodes (in a cluster)
- Portability of application logic
- Supports integration of multiple resource managers
- Disadvantages
  - increased communication



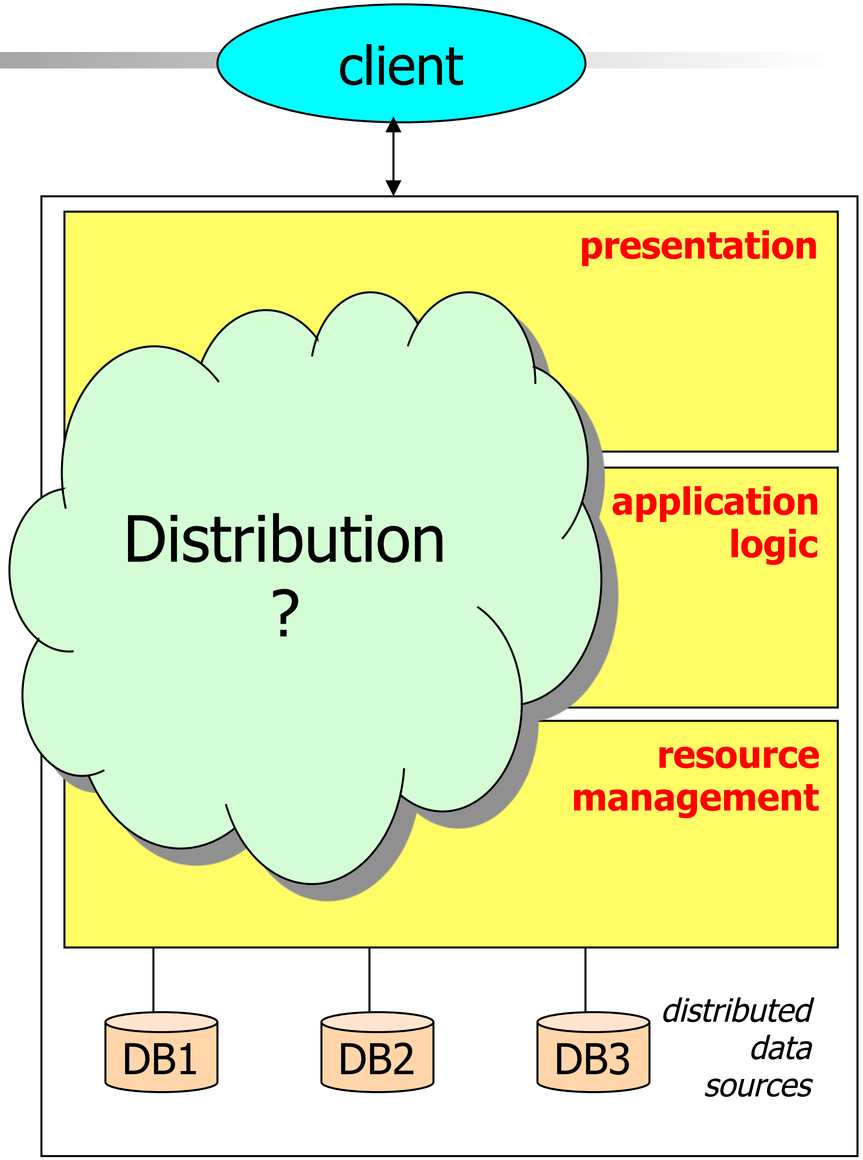
N-Tier Architecture

- Further generalizes 3-tier architecture
- Resource layer may include 1-, 2-, 3-, N-tiered systems
  - focus on linking, integration of different systems
- Presentation layer may be realized in separate tiers
  - especially important for supporting internet connectivity
    - client using browser
    - server-side presentation done by web server, dynamic HTML generation (HTML filter)
  - usually results in 4-tier architecture



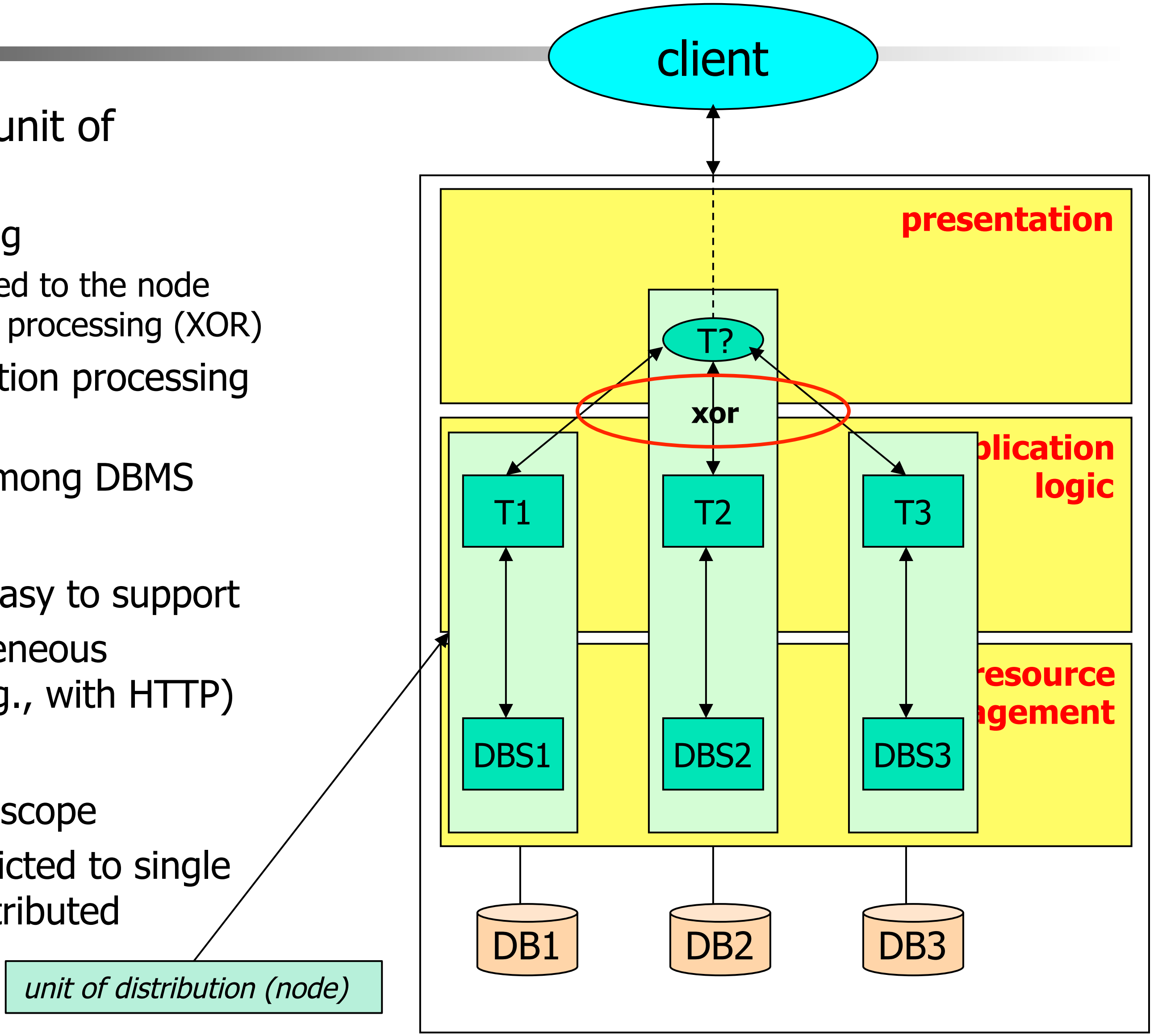
Distributed IS

- Why distribution?
  - economic reasons
    - e.g., reduced hardware cost
  - organizational reasons
    - local support of org. structures
    - integration of existing (legacy) data sources or application systems
    - local autonomy
  - technical reasons
    - increase performance (locality of processing, exploit parallelism)
    - high availability and reliability (replication)
    - scalability
- Client view
  - distribution transparency
  - single system image
- Different realization alternatives
  - often used in combination



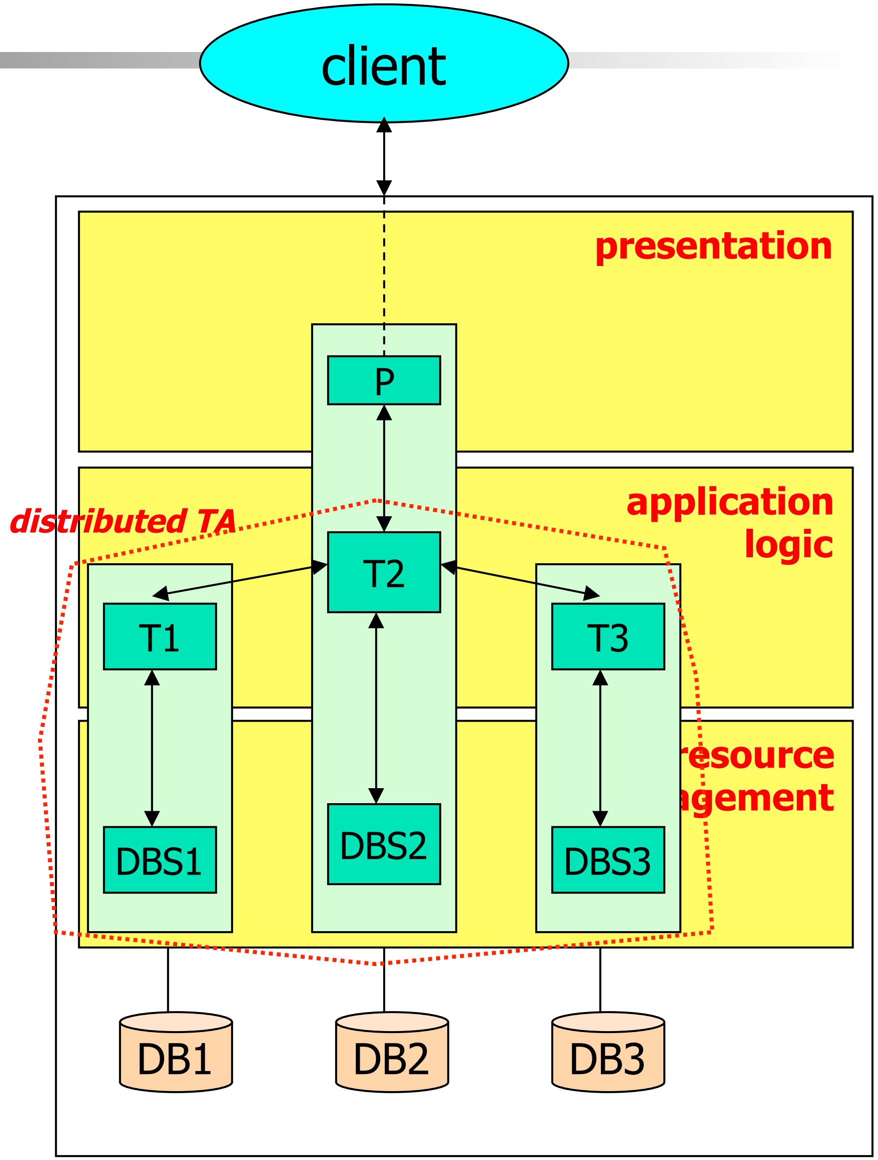
Alternative 1

- Transaction as the unit of distribution
  - transaction routing
    - request is routed to the node responsible for processing (XOR)
  - only local transaction processing (within a node)
  - no cooperation among DBMS
- Pros
  - simple solution, easy to support
  - works in heterogeneous environments (e.g., with HTTP)
- Cons
  - inflexible, limited scope
  - transactions restricted to single node (i.e., no distributed transactions)



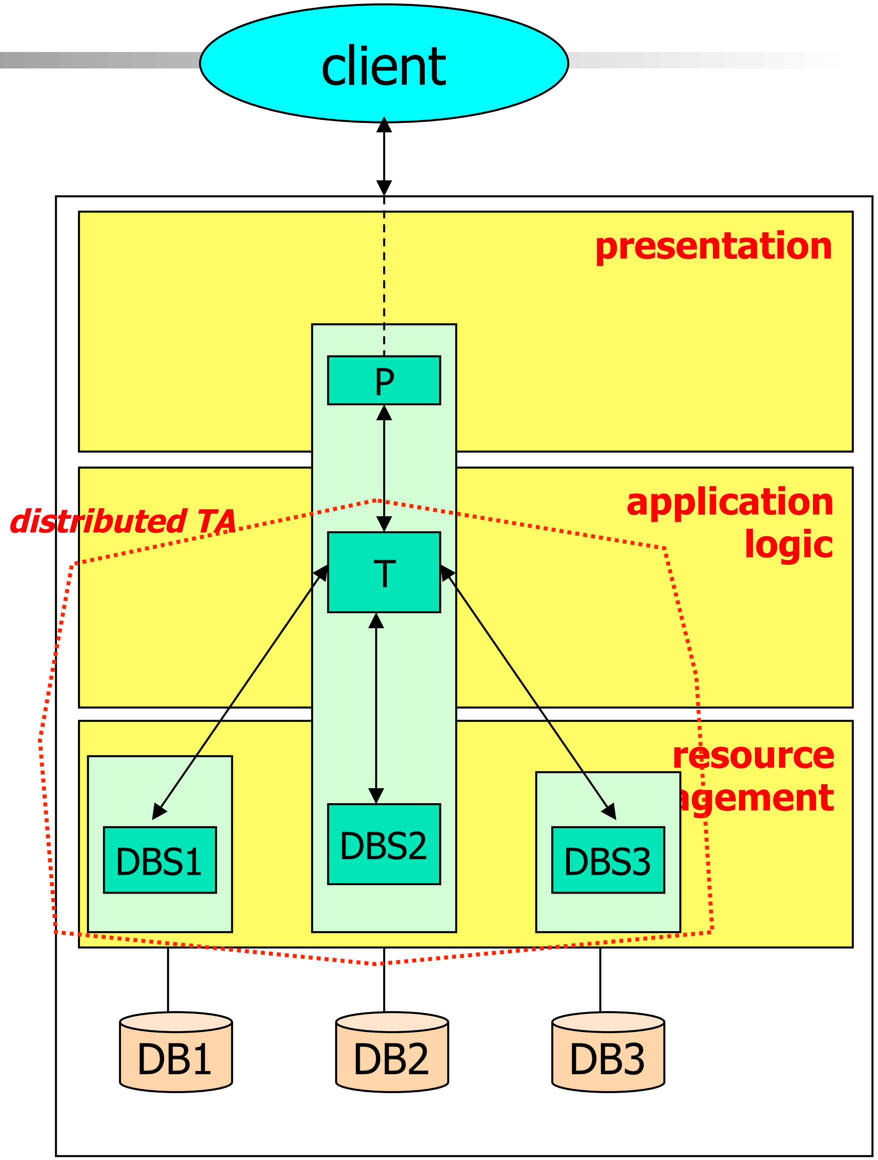
Alternative 2

- Application program/component as the unit of distribution
  - invocation of (remote) program components through RPC/RMI-based mechanisms
    - RPC, CORBA/EJB-RMI, Stored Procedures, …
    - "programmed" distribution
    - middleware can help to achieve location transparency
  - each program (component) accesses local DB only
  - distributed transaction processing
    - coordinated by TP-monitor/application server
    - supported by (local) application server and DBMSs
- Pros
  - locality of processing (low communication overhead)
  - supports application reuse, heterogeneous data sources
- Cons
  - inflexibility regarding data access operations
  - potential programming model complexity (distribution, error handling, …)
  - DB access operation cannot reach across multiple nodes



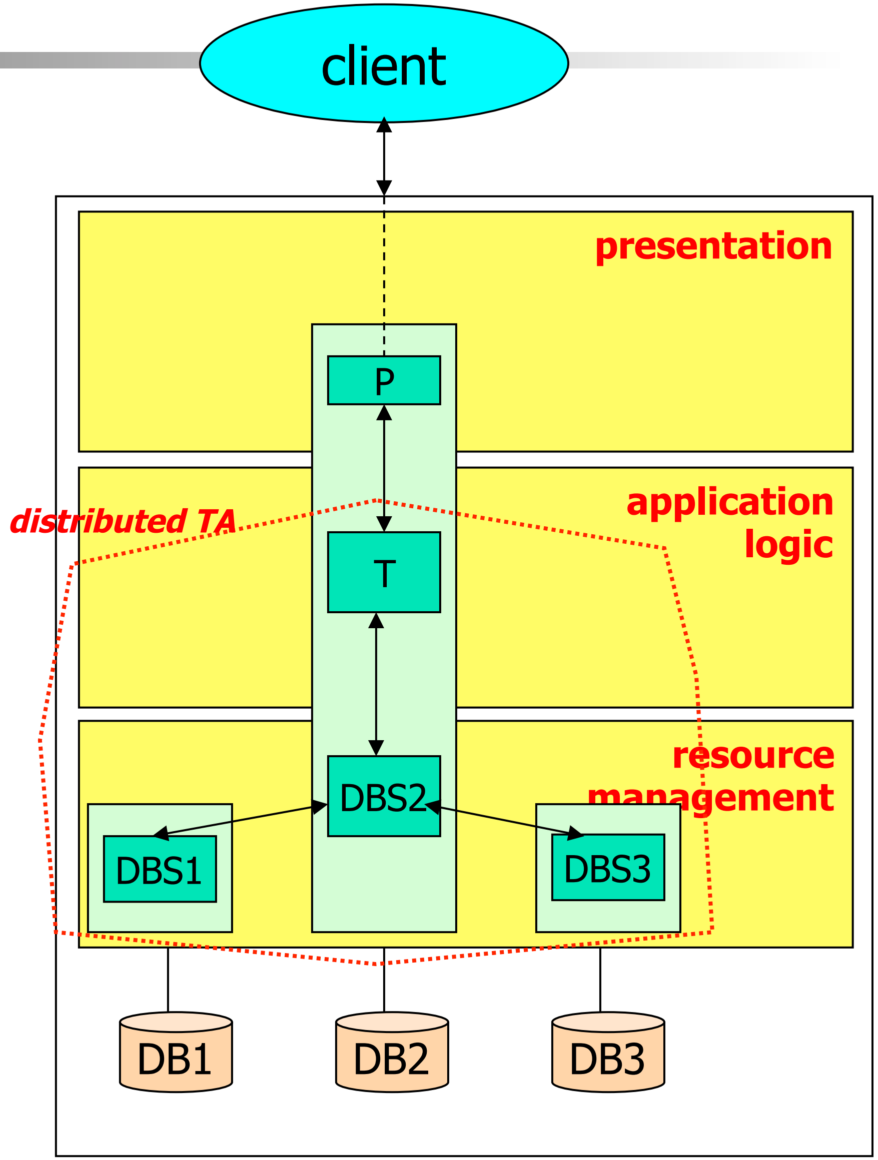
Alternative 3

- DB operation as the unit of distribution
  - Application can access remote data sources
    - function request shipping, data access services
    - (proprietary) DBMS client software
    - DB-gateways
  - Programmer aware of multiple databases
    - multiple schemas
    - each DB operation restricted to a single DB/schema
  - Distributed transaction processing
    - similar to alternative 2
- Pros
  - high flexibility for data access
- Cons
  - potentially increased communication overhead
  - programming model complexity
    - multiple DBs, schemas
    - heterogeneity of data sources, access APIs, …



Alternative 4

- Distribution controlled by DBMS/ middleware (e.g., federated DBMS)
  - single logical DB and DB-schema for application programmer
  - distributed transaction processing
    - see alternatives 2 and 3
  - DB-operation may span across multiple data sources
- Pros
  - high flexibility for data access
  - simple, powerful programming model
    - query language, integrated schema
- Cons
  - potentially increased communication overhead
  - schema integration required (see "EIS")

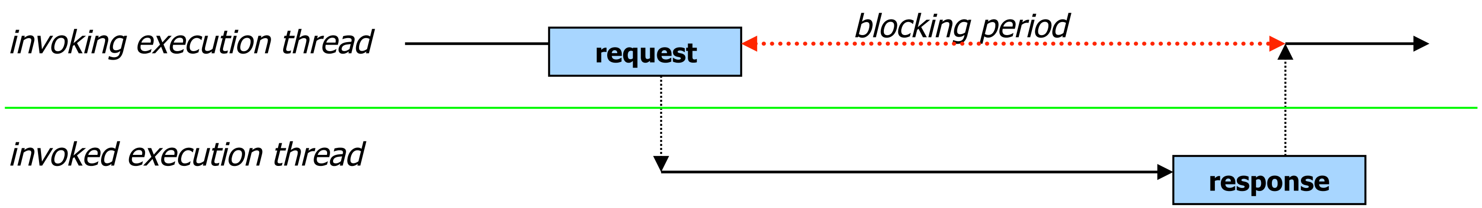


Communication in an Information System

- Blocking and non-blocking interactions
  - "synchronous" and "asynchronous" are accepted synonyms in our context
    - formal definition of synchronous involves additional aspects (transmission time), which we are ignoring here
  - interactions is
    - synchronous/blocking, if the involved parties must wait for interaction to conclude before doing anything else
    - asynchronous/non-blocking, otherwise

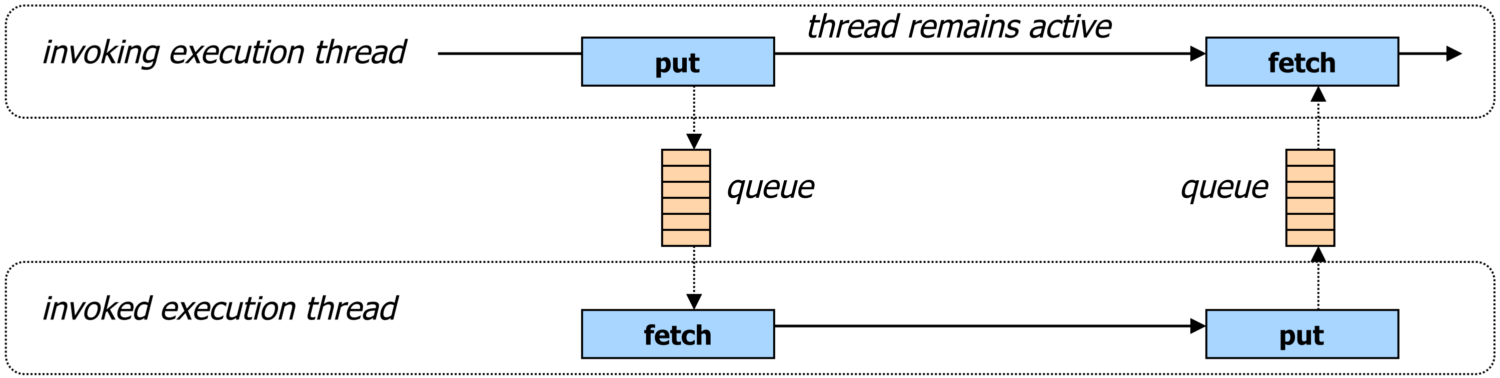
Synchronous or Blocking Calls

- Thread of execution at the requestor side must wait until response comes back
- Advantage: Easier to understand for the programmer
  - state of calling thread will not change before response comes back
  - code for invoking a service and processing the response are next to each other
- Disadvantage: Calling thread must wait, even if a response is not needed (right away) for further processing steps
  - waste of time, resources
    - blocking process may be swapped out of memory
    - running out of available connections
  - tight coupling of components/tiers
    - fault tolerance: both parties must be online, work properly for the entire duration of call
    - system maintenance: server maintenance forces client downtime



Asynchronous or Non-Blocking Calls

- Thread of execution at requestor side is not blocked
  - can continue working to perform other tasks
  - check for a response message at a later point, if needed
- Message queues
  - intermediate storage for messages until receiver is ready to retrieve them
  - more detail: chapters on message-oriented middleware
- Can be used in request-response interactions
  - requester "actively waits"
  - handle load peaks
- Supports other types of interaction
  - information dissemination, publish/subscribe



Middleware

- Middleware
  - supports the development, deployment, and execution of complex information systems
  - facilitates **interaction** between and **integration** of applications

  across multiple distributed, heterogeneous platforms and data sources
- Wide range of middleware, at every IS layer
  - integrating databases on a LAN
  - integrating complete 3-tier systems within a company
  - linking business partners across company boundaries
  - …

Two major aspects

- Middleware as a programming abstraction
  - hide complexities of building IS
    - distribution
    - communication
    - data access, persistence
    - error/failure handling
    - transaction support
- Middleware as infrastructure
  - realizes complex software infrastructure that implements programming abstractions
    - development
    - deployment
      - code generation, application "assembly"
    - runtime execution

Summary

- Distributed Transactions for achieving global atomicity
  - 2PC, hierarchical 2PC
  - fundamental concept in distributed IS
- Logical layers of an information system
  - presentation, application logic, resource management
- Design strategies
  - ideally top-down, but usually bottom-up (out of necessity)
- Architectures
  - 1-tier, 2-tier, 3-tier, n-tier
  - flexibility, distribution options vs. performance, complexity, manageability
- Distribution alternatives
  - units of distribution, pros and cons
- Communication
  - synchronous, asynchronous