Distributed Systems

Summer Term 2020

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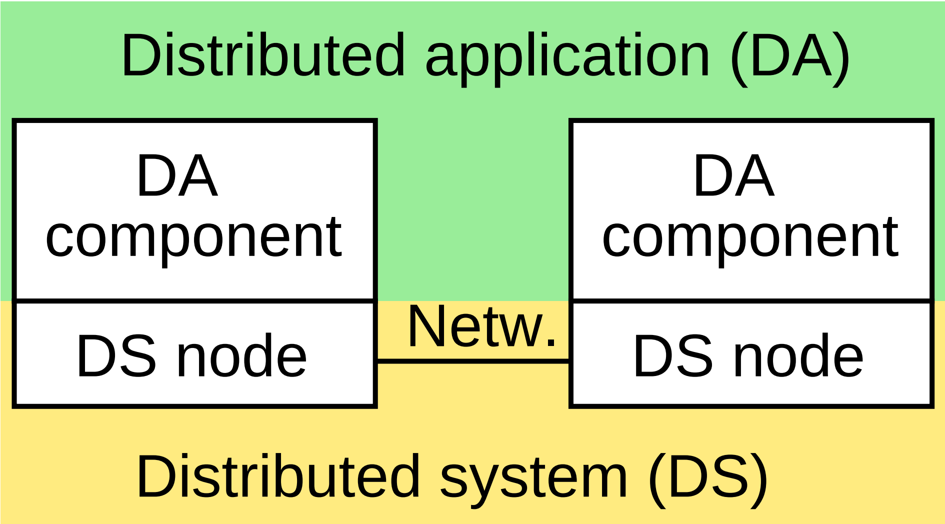
2 Middleware

Content

- Communication in distributed systems
- Communication-oriented middleware
- Application-oriented middleware

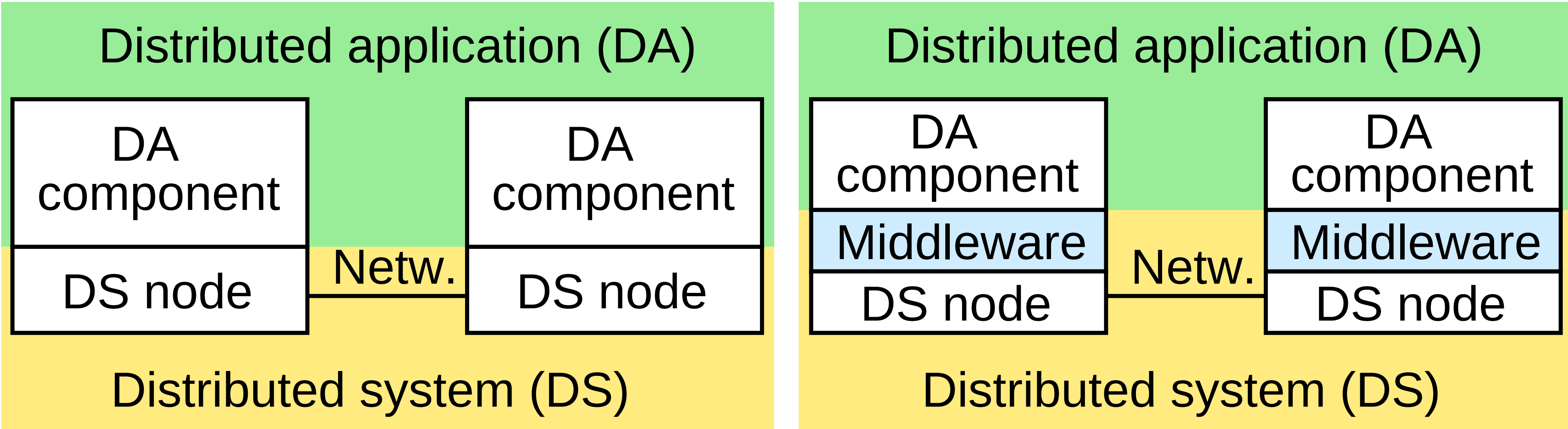
Literature

- Hammerschall: Ch. 2, 6
- Tanenbaum, van Steen: Ch. 2
- Colouris, Dollimore, Kindberg: Ch. 4.4



- DA uses DS for communication between its components
- DSs generally only offer simple communication services
  - direct use: **network programming**
- **Middleware** offers more intelligent interfaces
  - hides details of network programming

2 Middleware ...



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- **Middleware** offers more intelligent interfaces
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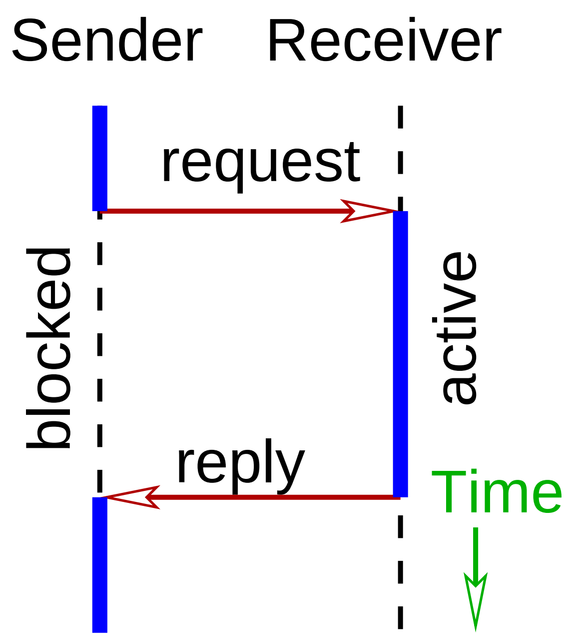
- Middleware is the interface between distributed application and distributed system
- Goal: hide distribution aspects from application
  - transparency (☞ **1.3**)
- Middleware can also provide additional services for applications
  - huge differences in existing middleware
- Distinction:
  - **communication-oriented middleware** (☞ **2.2**)
    - (only) abstraction from network programming
  - **application-oriented middleware** (☞ **2.3**)
    - besides communication, the focus is on support of distributed applications

2.1 Communication in Distributed Systems

- Basis: **interprocess communication (IPC)**
  - exchange of messages between processes (☞ **BS_I: 3.2**)
    - on the same or on different nodes
    - e.g. via ports, mailboxes, streams, ...
- For distribution: network protocols (☞ **RN_I**)
  - relevant topics etc: addressing, reliability, guaranteed ordering, timeouts, acknowledgements, marshalling
- Interface for network programming: sockets (☞ **RN_II**)
  - datagrams (UDP) and streams (TCP)

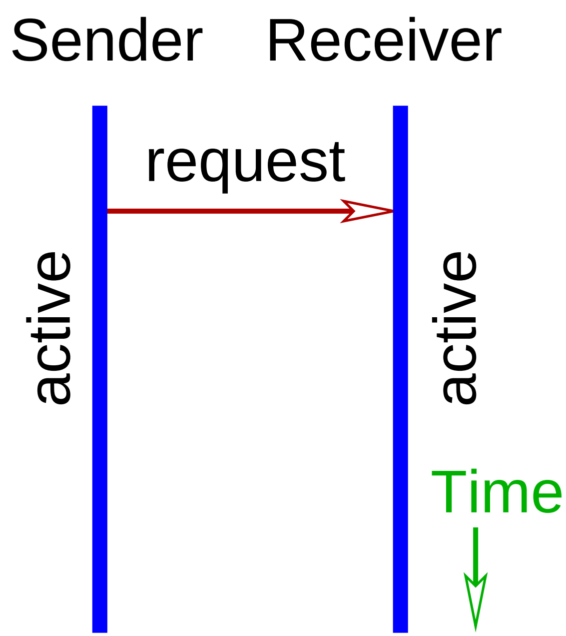
Synchronous Communication



- Sender and receiver block when calling a send or receive operation
  - receiver is waiting for a request
  - sender is waiting for the reply
- Tight coupling between sender and receivers
  - advantage: easy to understand model
  - disadvantage: strong dependency, especially in case of error
- Prerequisites:
  - reliable and fast network connection
  - receiver process is available

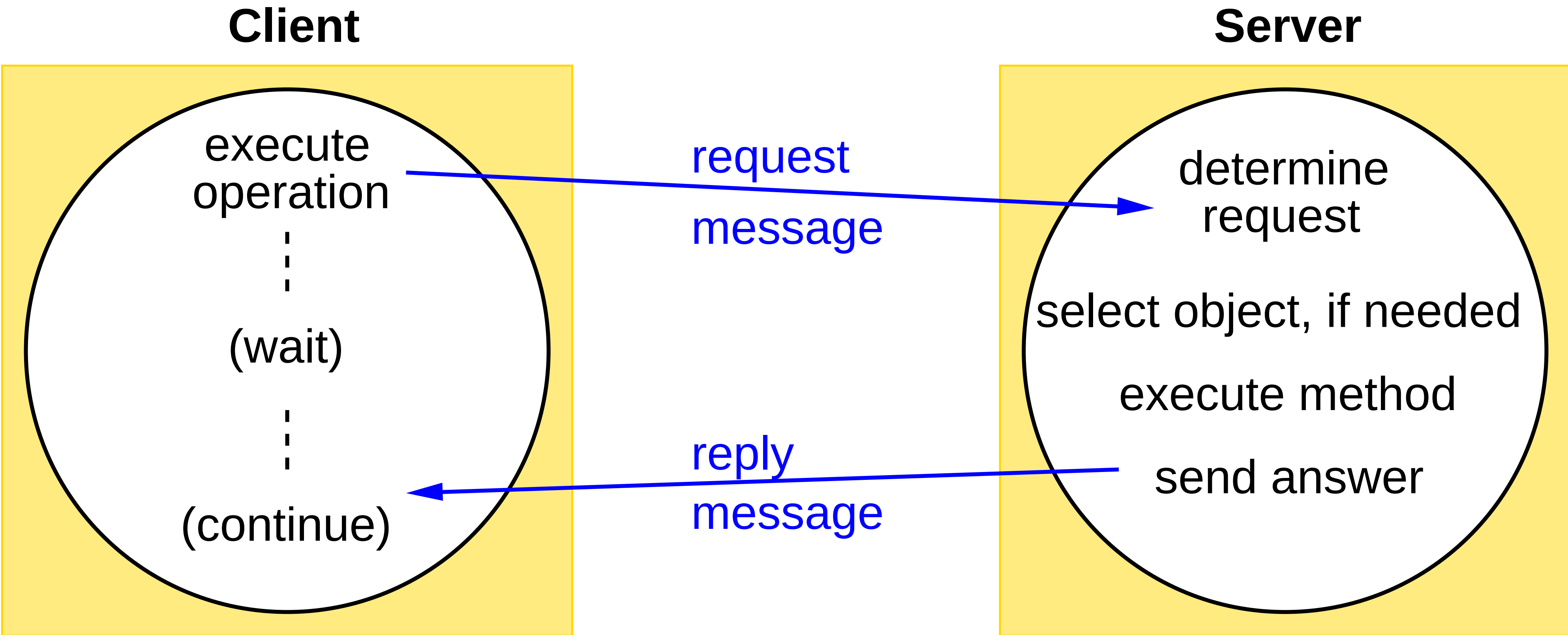
Asynchronous Communication

- Sender is not blocked, can continue immediately after sending the message
- Incoming messages are buffered at the receiver
- Answers are optional
  - receiver can reply asynchronously to the sender



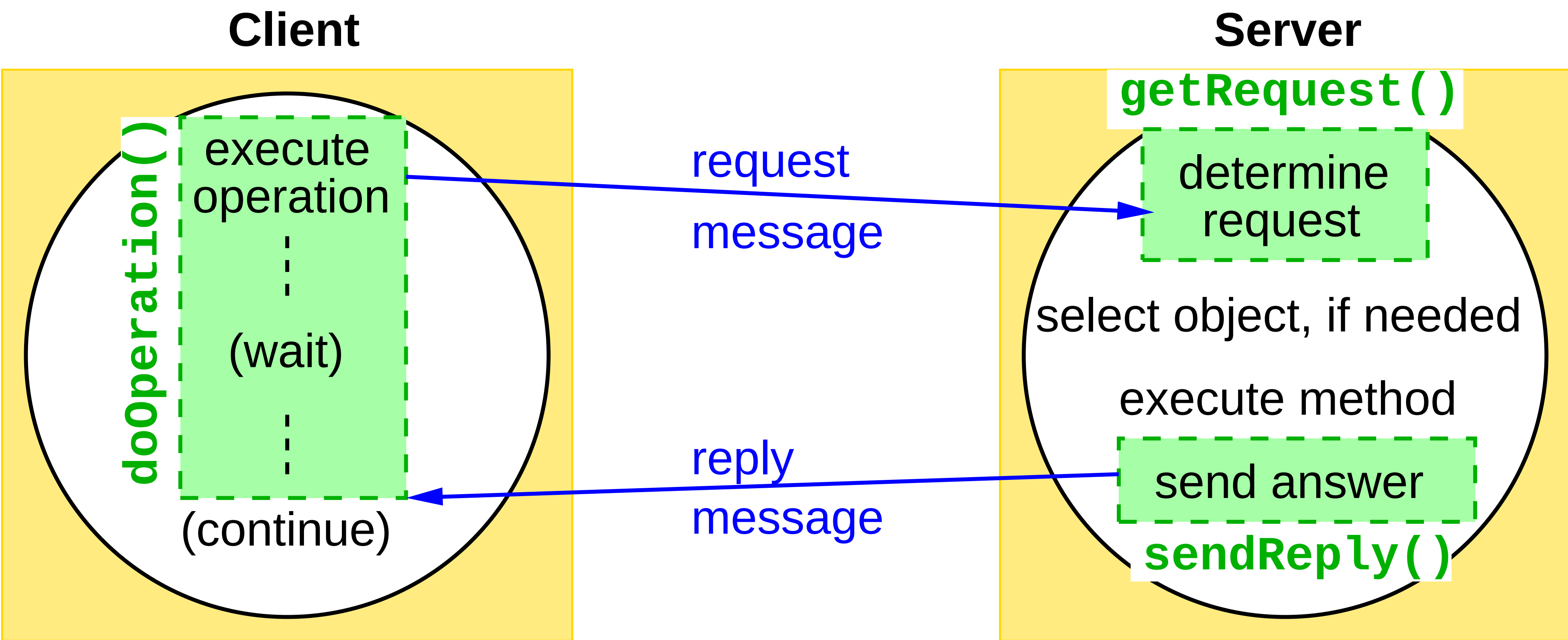
- More complex implementation and use as with synchronous communication, but usually more efficient
- Only loose coupling between the processes
  - receiver does not have to be ready for reception
  - less dependent in case of errors

Client/Server Communication



- Mostly synchronous: client blocked until response arrives
- Variants: asynchronous (non blocking), one way (without answer)

Client/Server Communication



- ➥ Mostly synchronous: client blocked until response arrives
- ➥ Variants: asynchronous (non blocking), one way (without answer)

Client/Server Communication: Request/Response Protocol

- Typical operations:
  - `doOperation()` – send request and wait for result
  - `getRequest()` – wait for request
  - `sendReply()` – send result
- Typical message structure:

messageType	request / reply ?
requestID	unique ID of request (usually int)
objectReference	reference to remote object (if needed)
methodID	method to be called (int / String)
arguments	arguments (usually as Byte array)

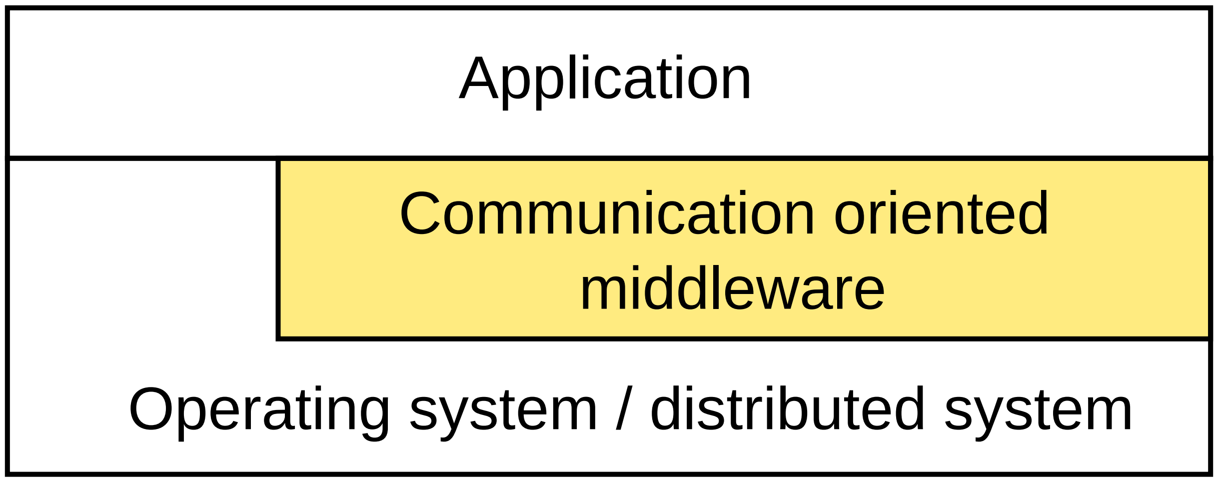
  - request ID + sender ID result in unique message ID
    - e.g. to map an answer to its query

Client/Server Communication: Error Handling

- Request and/or response messages may be lost
- Client sets a timeout when sending a request
  - after expiration, request is usually sent again
  - after a few repetitions: termination with exception
- Server discards duplicate requests if request has already been / is still being processed
- For lost response messages:
  - idempotent operations can be executed again
  - otherwise: save results of operations in a history
    - for repeated request: only resend the result
    - delete history entries when next request arrives; if necessary confirmations for results can also be used

2.2 Communication-oriented Middleware

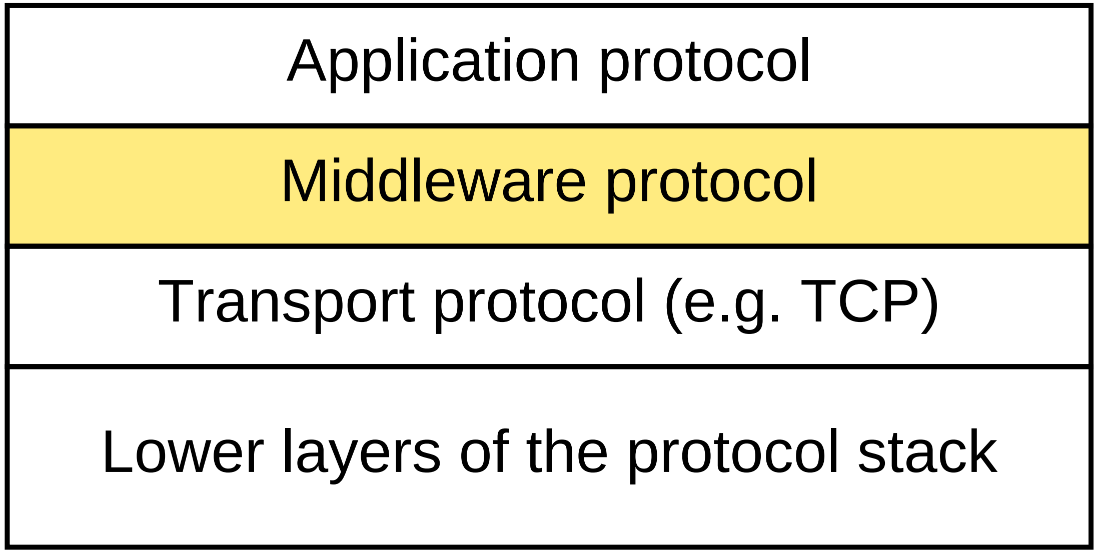
- Focus: provision of a communication infrastructure for distributed applications
- Tasks:
  - communication
  - dealing with heterogeneity
  - error handling



2.2.1 Tasks of the Middleware

Communication

- ➥ Provision of a middleware protocol
- ➥ Localization and identification of communication partners
- ➥ Integration with process and thread management



Heterogeneity

- Problem with data transmission:
  - heterogeneity in distributed systems
- Heterogeneous hardware and operating systems
  - different byte order
    - little endian vs. big endian
  - different character encoding
    - e.g.. ASCII / Unicode / UTF-8 / EBCDIC (IBM Mainframes)
- Heterogeneous programming languages
  - different representation of simple and complex data types in the main memory

Heterogeneity: Solutions (☞ RN_I)

- Use of generic, standardized data formats
  - known to all communication partners and middleware
  - platform-specific formats for middleware (e.g. CDR for CORBA) or external formats, e.g. XML
- Heterogeneity of hardware and operating system
  - is handled transparently for the applications by the middleware
- Heterogeneity of programming languages
  - applications need to convert data to higher-level format and back (**marshaling** / **unmarshaling**)
    - necessary code is usually generated automatically
      - client stub / server skeleton

Error Handling

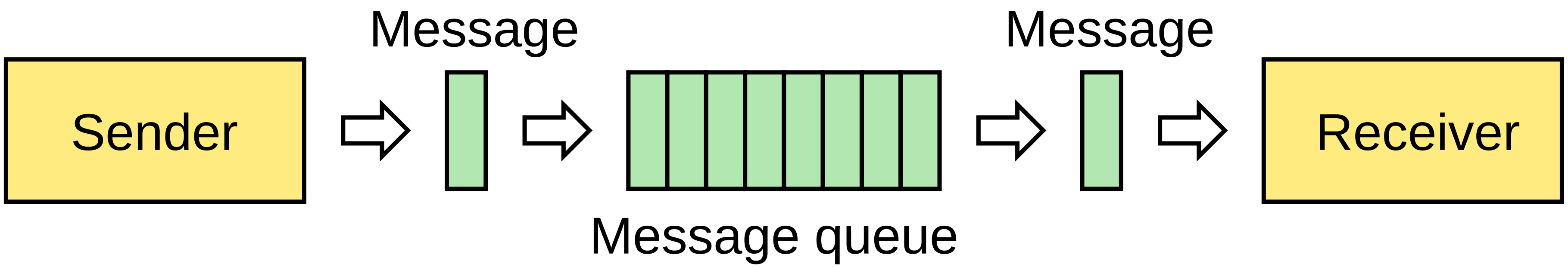
- Possible errors due to distribution
  - incorrect transmission (incl. loss of messages)
    - handled by the protocols of the distributed system:
      - checksums, CRC
      - retransmission of packets (e.g. TCP)
  - failure of components (network, hardware, software)
    - handled by middleware or application:
      - acceptance of the error
      - retransmission of messages
      - replication of components (error avoidance)
      - controlled termination of the application

2.2.2 Programming Models

- Programming model defines two concepts:
  - communication model
    - synchronous vs. asynchronous
  - programming paradigm
    - object-oriented vs. procedural
- Three common programming models for middleware:
  - message-oriented model (asynchronous / arbitrary)
  - remote procedure call (synchronous / procedural)
  - remote method invocation (synchronous / object-oriented)

Message-Oriented Model

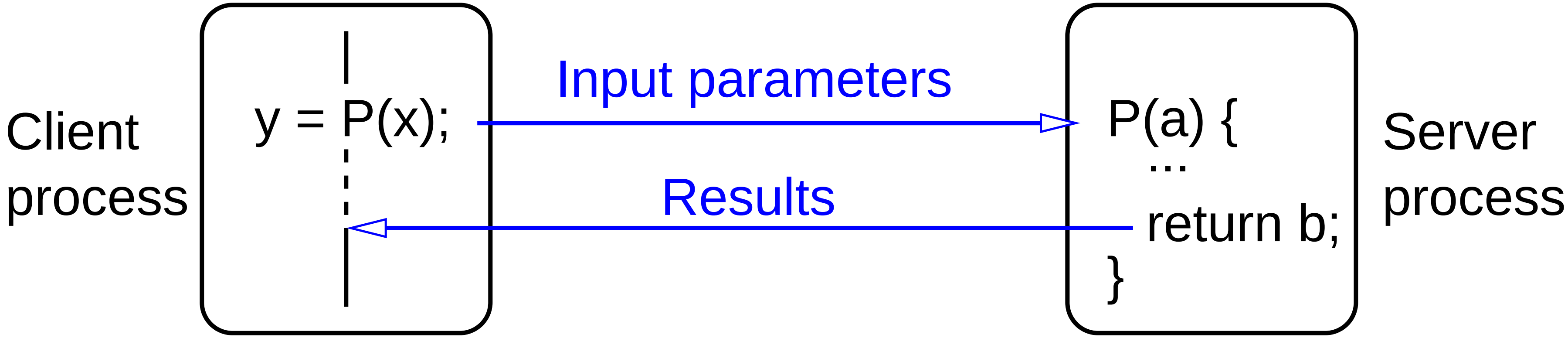
- Sender puts message in receiver's queue



- Receiver accepts message as soon as he is ready
- Extensive decoupling of transmitter and receiver
- No method or procedure calls
  - data is packed and sent by the application
  - no automatic reply message

Remote Procedure Call (RPC)

- Allows a client to call a procedure in a remote server process



- Communication according to request / response principle

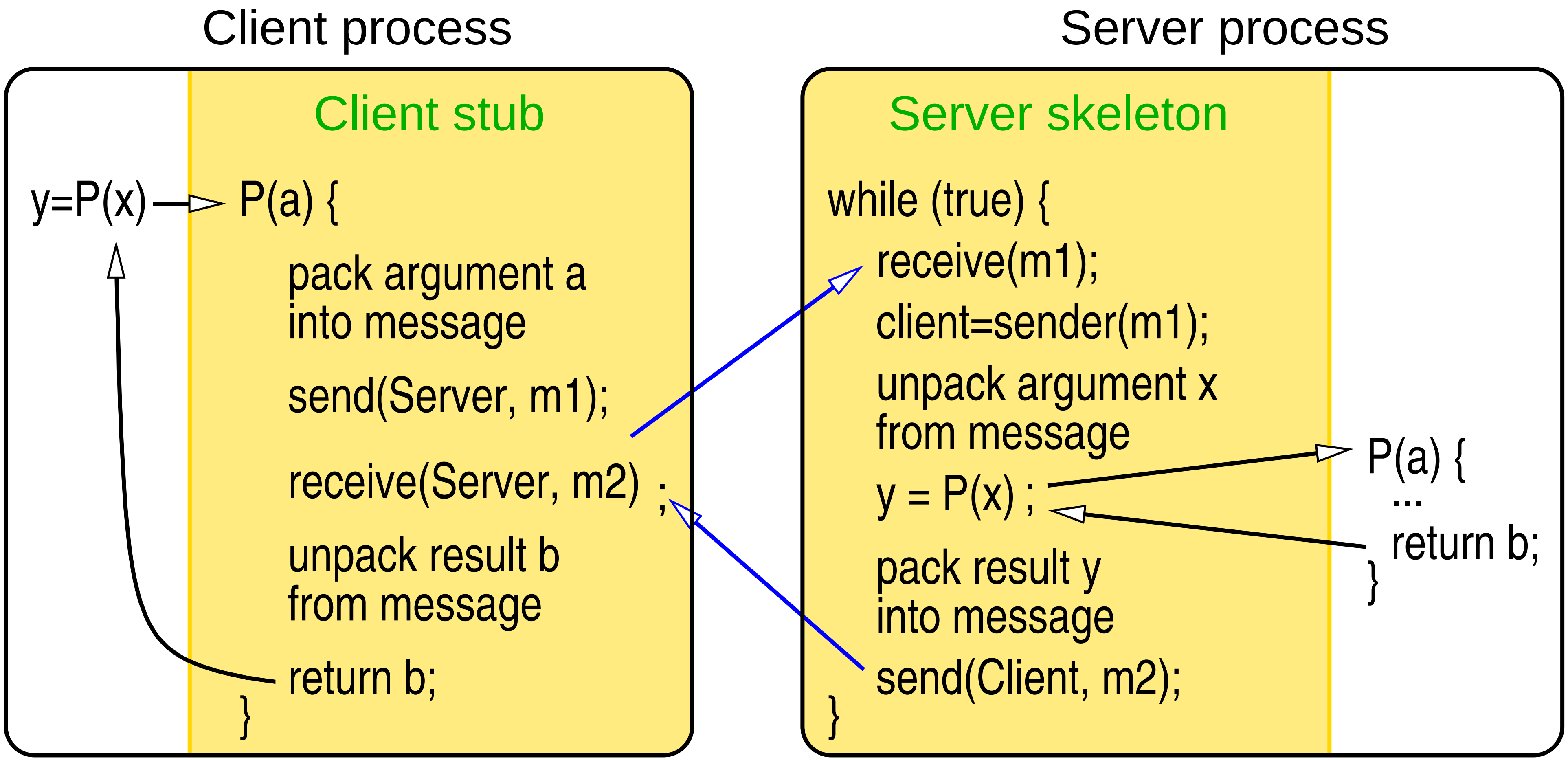
Remote Method Invocation (RMI)

- Allows an object to call methods of a remote object
- In principle very similar to RPC

Common Basic Concepts of Remote Calls

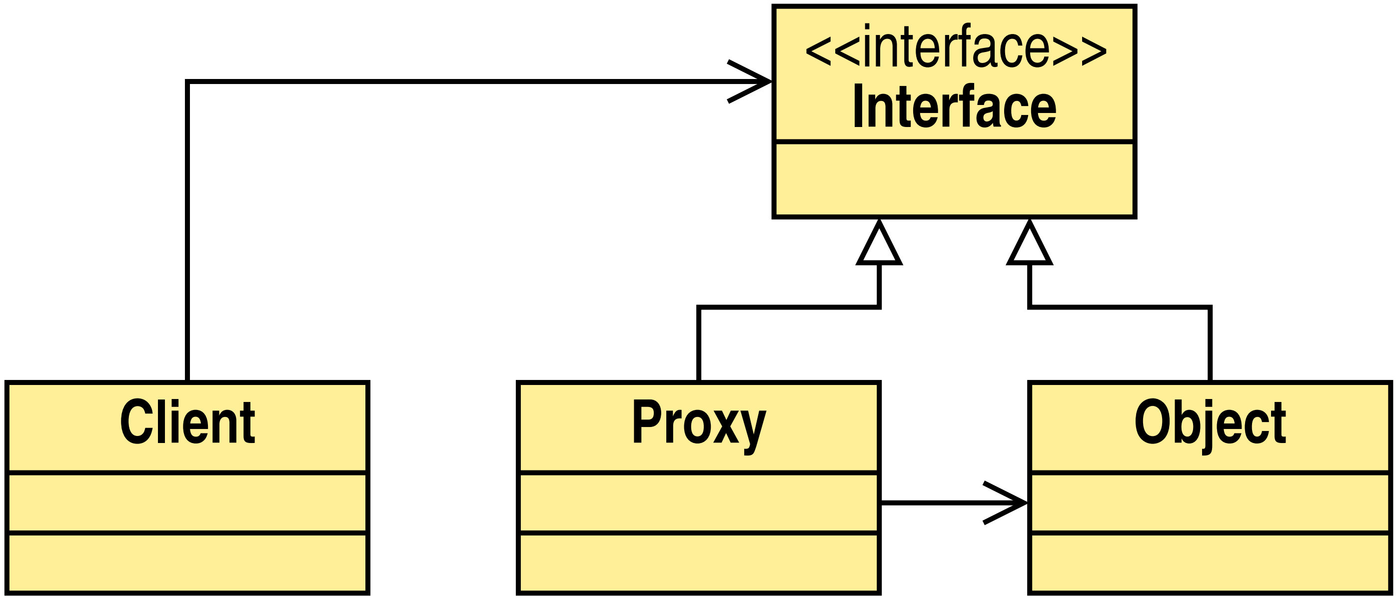
- Client and server are decoupled by interface definition
  - defines names of calls, parameters and return values
- Introduction of **client stubs** and **server skeletons** as an access interface
  - are automatically generated from interface definition
    - IDL compiler (IDL = interface definition language)
  - are responsible for marshaling / unmarshaling as well as for the actual communication
  - realize access and location transparency

How Client Stub and Server Skeleton Work (RPC)

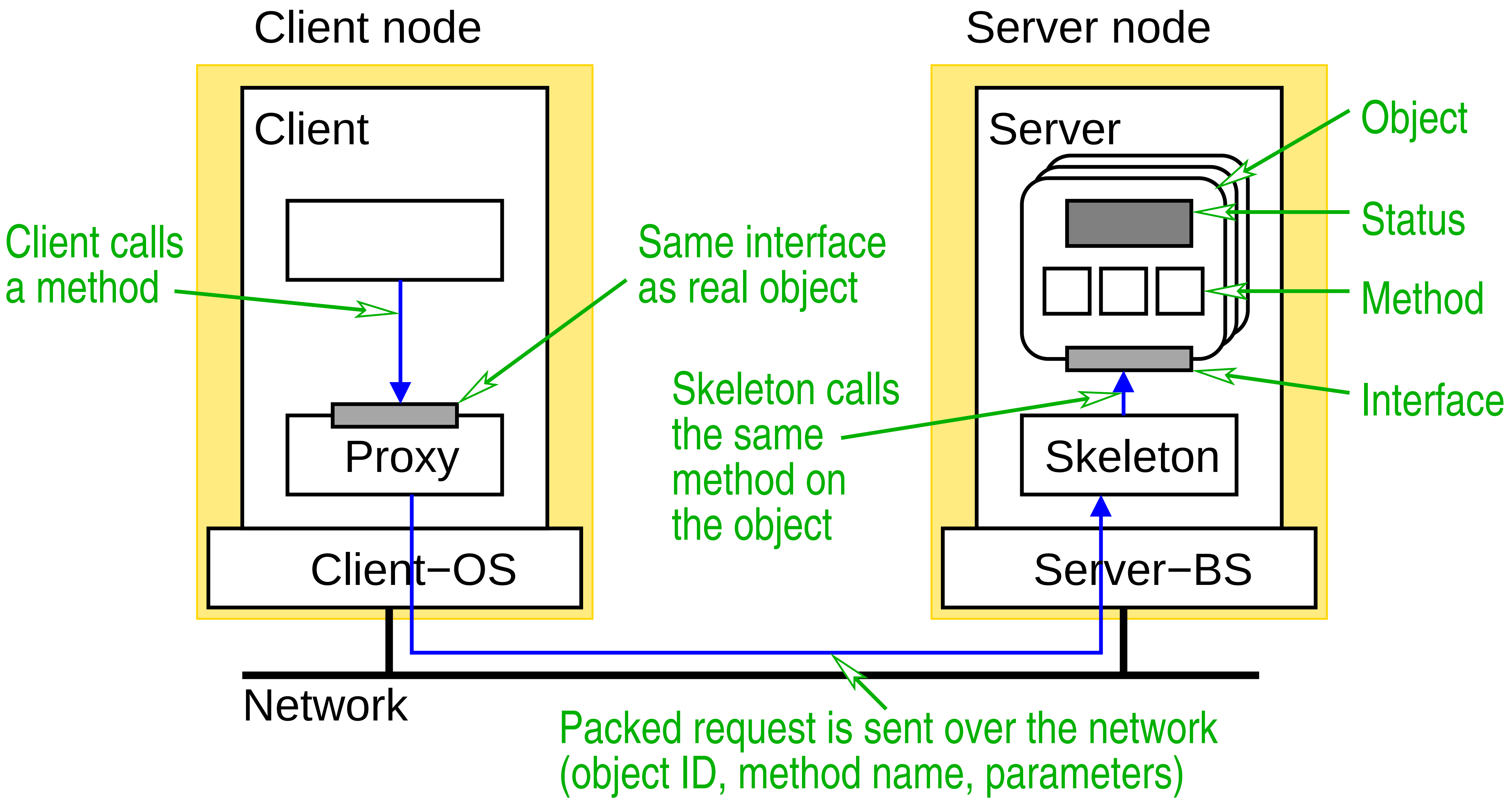


Basis of RMI: The Proxy Pattern

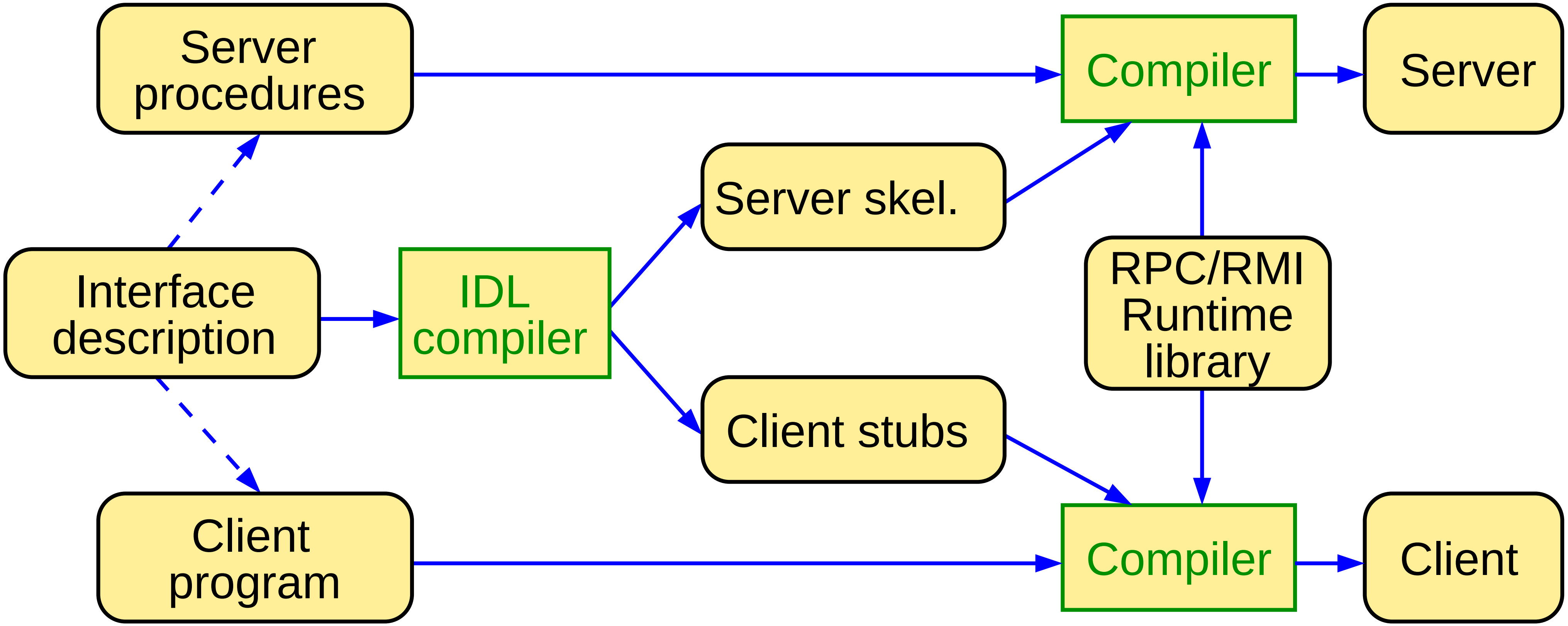
- Client works with a deputy object (**proxy**) of the actual server object
  - proxy and server object implement the same interface
  - client only knows / uses this interface



Flow of a Remote Method Call



Creation of a Client/Server Program



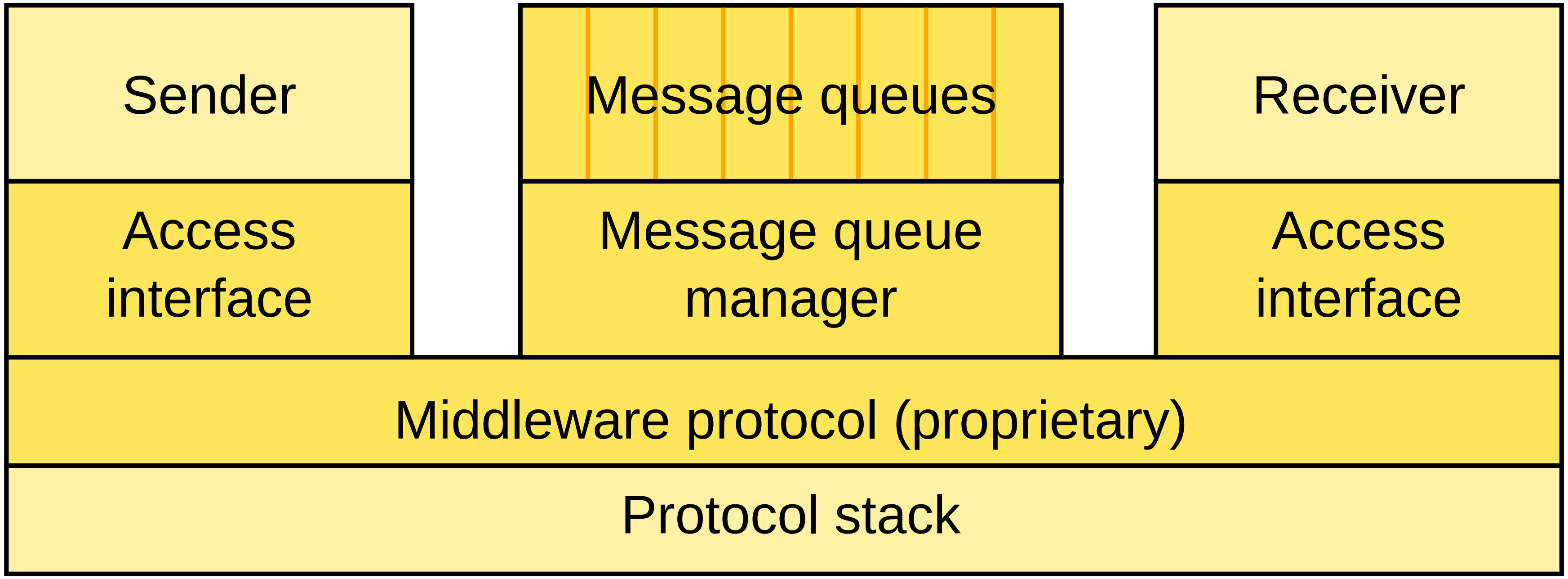
- Applies in principle to all realizations of remote calls

2.2.3 Middleware Technologies

- Realize (at least) one of the programming models
  - rely on open standards / standardized interfaces
- Remote procedure call
  - SUN RPC, DCE RPC, Web Services (☞ **CSP: 7**), ...
- Remote method invocation
  - Java RMI (☞ **3**), CORBA (☞ **CSP: 3**), ...
- Message-oriented middleware technologies
  - MOM: message oriented middleware, messaging systems
  - mainly for EAI
  - Java Message Service, WebSphereMQ (MQSeries), ...

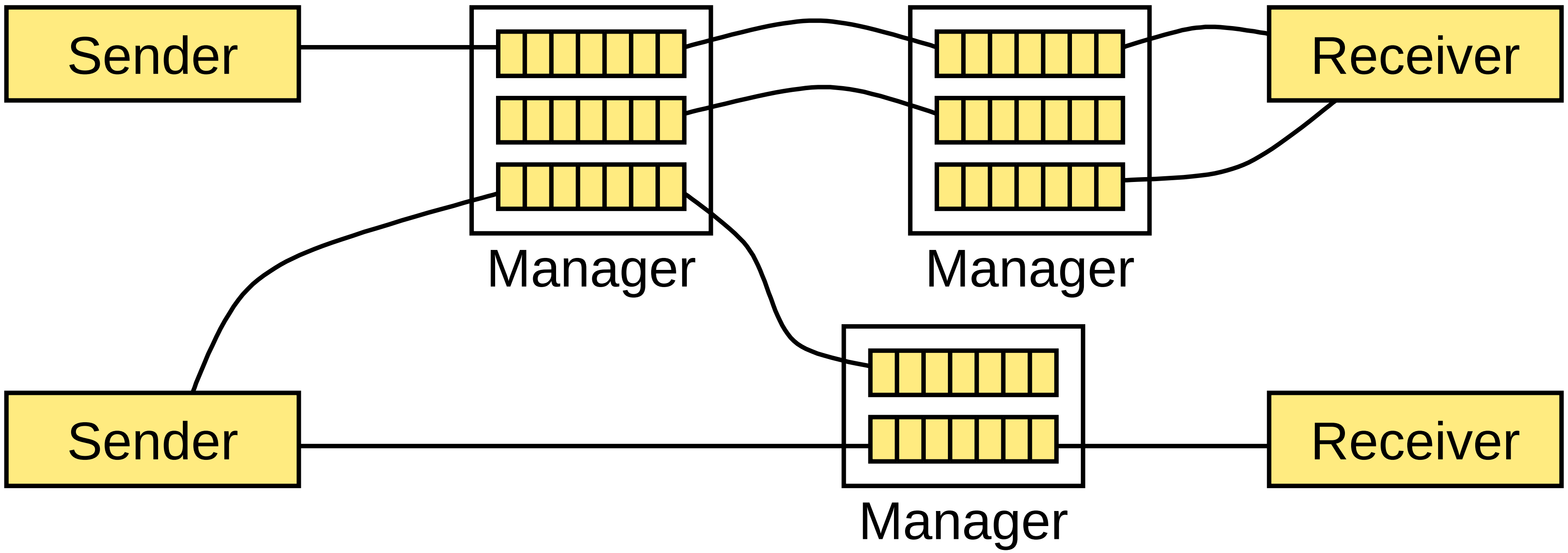
2.2.4 Message Oriented Middleware (MOM)

- Middleware technology for the message-oriented model
- In addition to message exchange also other services, especially queue management



Message Queue Infrastructure

- Access to queues is only possible locally
  - local: same computer or same subnet
- Transport of messages across subnet boundaries by queue administrators (routers)



Variants of message exchange

- Point-to-point communication
  - communication between two defined processes
  - simplest model: asynchronous communication
  - enhancement: request/reply model
    - enables synchronous communication via asynchronous middleware
- Broadcast communication
  - Message is sent to all reachable receivers
  - one implementation: publish/subscribe model
    - publishers publish messages/news on a topic
    - subscribers subscriber to certain topics
    - mediation via a broker

Example: Java Message Service

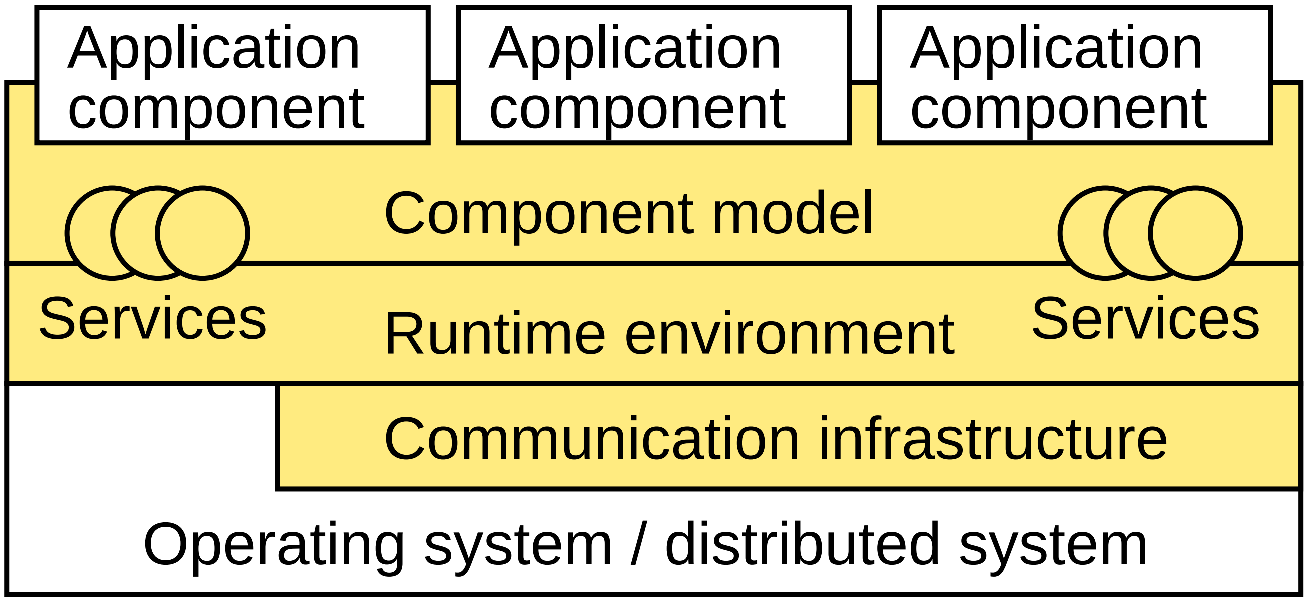
- Part of the Java Enterprise Edition (Java EE)
- Unified Java interface for MOM services
- Distinguishes two roles:
  - JMS provider: the respective MOM server
  - JMS client: sender or receiver of messages
- JMS supports:
  - asynchronous point-to-point communication
  - request/reply model
  - publish/subscribe model
- JMS defines corresponding access objects and methods

2.2.5 Summary

- Tasks: Communication, dealing with heterogeneity, error handling
- Programming models:
  - message-oriented model (asynchronous)
    - basis: message queues
    - refinements:
      - request/reply model (synchronous)
      - publish/subscribe model (broadcast)
  - remote procedure or method calls
    - synchronous: request and response
    - generated stubs for (un-)marshaling

2.3 Application-oriented Middleware

- Based on communication-oriented middleware
- Extends it by:
  - runtime environment
  - services
  - component model



2.3.1 Runtime environment

- Based on node operating systems of the distributed system
  - Operating system (OS) manages processes, memory, I/O, ...
  - provides basic functionality
    - starting / stopping processes, scheduling, ...
    - interprocess communication, synchronization, ...
- Runtime environment extends functionality of the OS:
  - improved resource management
    - e.g. concurrency, connection management
  - improved availability
  - improved security mechanisms

Resource management

- Middleware goes beyond simple OS functionality
  - e.g. independently managed main memory areas with individual security criteria
  - pooling of processes, threads, connections
    - are created for stock and made available as required
  - possible, since middleware is specific to certain classes of applications
- Goal: improved performance, scalability and availability

Concurrency

- Concurrency in this context:
  - isolated parallel processing of requests
- Concurrency can be implemented via processes or threads
  - threads (lightweight processes): concurrent activities within processes
    - threads in the same process share all resources
  - advantages and disadvantages:
    - processes: high resource requirements, not well scalable, good protection, with low concurrency
    - threads: well scalable, no mutual protection, with high concurrency

Concurrency ...

- Middleware takes over automatic generation / administration of threads in the case of concurrent orders, e.g.
  - *single-threaded*
    - only one thread, sequential processing
  - *thread-per-request*
    - a new thread is created for each request
  - *thread-per-session*
    - a new thread is created for each session (client)
  - *thread pool*
    - fixed number of threads, incoming requests are distributed automatically
      - saves thread generation costs
      - limits resource consumption

Connection management

- Connection here means: endpoints of communication channels
  - occur at tier boundaries (between process spaces)
    - e.g. client/server interface, database access
  - are assigned to a process/thread, if in the active state
  - require resources (memory, processor time)
  - opening and closing connections is costly
- To save resources: pooling of connections
  - connections are initialized to stock and placed in pool
  - each thread/process receives a connection on demand
  - after use: return connection to pool

Availability

- Requirement to the application,
  but mainly implemented by the runtime environment
- Downtimes are caused by
  - failure of a hardware or software component
  - overload of a hardware or software component
  - maintenance of a hardware or software component
- Frequent technology for ensuring availability: cluster
  - replication of hardware and software
  - cluster appears externally as one unit
  - two types: fail-over cluster / load-balancing cluster

Security

- Distributed applications are vulnerable due to their distribution
- Middleware supports different security models
- Security requirements:
  - **authentication**:
    - proves the identity of the user / a component
    - e.g. by password query (for users) or cryptographic techniques and certificates (for components)
  - **authorization**:
    - definition of access rights for users to specific services
      - or more fine grained: methods and attributes
    - requires secure authentication

Security ...

- Security requirements ...:
  - **confidentiality**
    - information cannot be intercepted during transmission in the network
    - technique: encryption
  - **integrity**
    - transmitted data cannot be changed without being noticed
    - techniques: cryptographic checksum (message digest, fingerprint), digital signature
      - digital signature also ensures authenticity of the sender

Security ...

- Security mechanisms:
  - encryption
    - symmetric (e.g. IDEA, AES)
      - same key for encryption and decryption
    - asymmetric (public key algorithms, e.g. RSA)
      - public key for encryption
      - private key for decrypting
  - digital signature
    - ensures integrity of a message and authenticity of the sender as well as nonrepudiation
  - certificate
    - certifies that public key and person (or component) belong together

2.3.2 Services

Name service (directory service) (☞ 4)

- Publication of available services
  - in the intranet or Internet
- Assignment of names to references (addresses)
  - name serves as a unique / unchangeable identifier
  - the client can request the address of a service via its name
    - address can change e.g. at restart
  - goal: decoupling of client and server
- Examples: JNDI, RMI registry, CORBA interoperable naming service, UDDI registry, LDAP server, ...

Session management

- In interactive systems: each instance of a client is assigned its own **session**
  - deleted when logging out or closing the client
- Session stores all relevant data (in main memory)
  - e.g. identification of the user, browser type, "‘shopping cart’", ...
  - data stored in the server or in the client
  - transient data: deleted at the end of the session
  - persistent data: is written to a data carrier (database) at the end of the session.
- Middleware implements/supports the assignment of requests to sessions (often transparent)
  - e.g. cookies, HTTP-sessions, session beans, ...

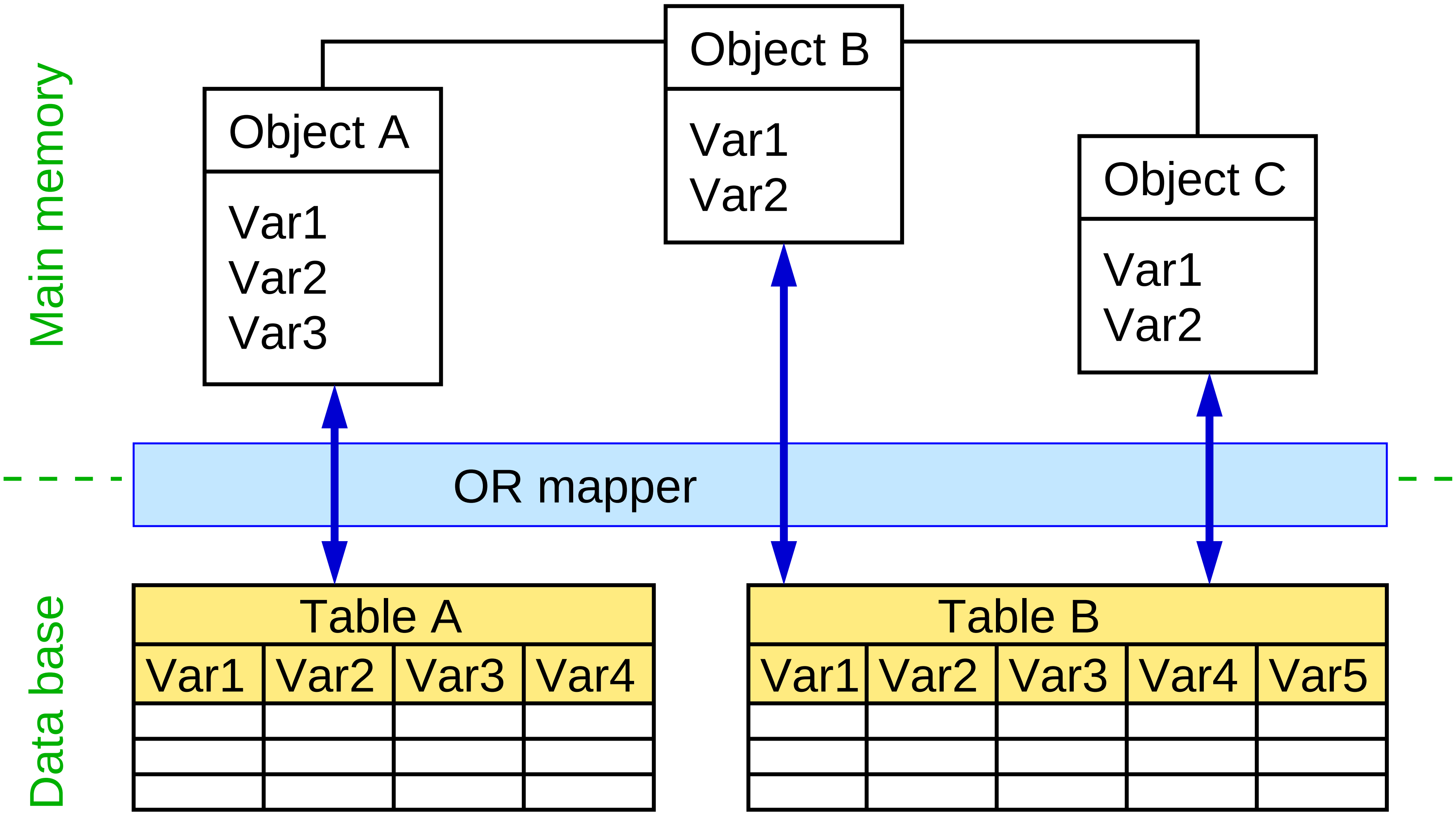
Transaction management (☞ 7.4)

- Service for interactive, data-centric applications
  - consistency / integrity of data is important
  - this means that the entire (maybe distributed) dataset must represent a valid state in itself
- Typical sequence in applications:
  1. client requests data
  2. client changes the data
  3. client requests that the data be rewritten
  - problem: steps 1-3 could be performed by two clients at the same time
- Transaction management allows execution of a sequence of actions as an atomic unit

Persistence service

- Persistence: all measures for the permanent storage of main memory data
- Persistence service: intelligent interface to the database
  - integrated in middleware or as an independent component
  - most important service for data-centered applications besides transaction management
- Most common type: object-relational mapper (OR-Mapper)
  - maps objects in the main memory to tables in a relational database
  - mapping rules are defined by application developers

Persistence service ...



2.3.3 Component model

- Components: “large” objects for structuring applications
- A component model defines:
  - the term “component”
    - structure and properties of the components
    - mandatory and optional interfaces
  - interface contracts
    - how do components interact with each other and with the runtime environment?
  - component runtime environment
    - management of the life cycle of components
    - implicit provision of services: component only specifies its requirements (e.g. persistence)

2.3.4 Middleware Technologies

- Object request broker (ORB)
  - distributed objects, remote method calls
  - variety of services, only basic runtime environment
  - example: CORBA
- Application server
  - focus: support of application logic (middle tier)
  - services, runtime environment, and component model
  - today only as part of a middleware platform
- Middleware platforms
  - extension of application servers: support of all tiers
    - distributed applications as well as EAI
  - examples: Java EE/EJB, .NET/COM, CORBA 3.0/CCM

2.3.5 Summary

Application-oriented middleware

- Runtime environment
  - resource management, availability, security
- Services
  - name service, session management, transaction management, persistence service
- Component model
  - defintion of components, interface contracts, runtime environment