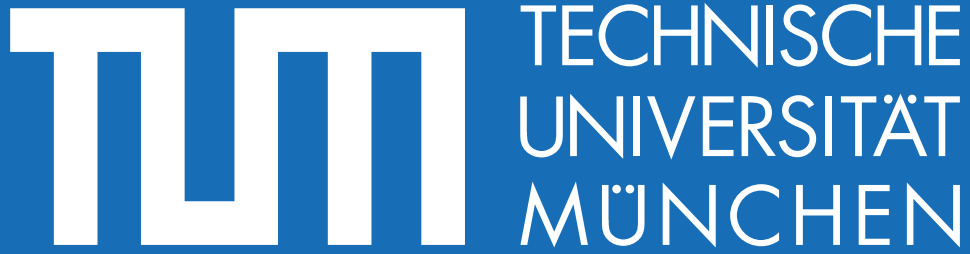


Software Engineering in Industrial Practice (SEIP)

Dr. Ralf S. Engelschall

ARCHITECTURE FUNDAMENTALS

Architecture Patterns

TECHNISCHE UNIVERSITÄT MÜNCHEN

AF 06.1

Pattern Definition

Pattern: unique, catchy, and associative **Name** and concise, precise, and normative **Description** of a contextual, regularly occurring, and practically relevant **Problem** and a general, highly reusable, and best practice **Solution** for it.

Pattern Structure

Pattern

- **Name**
  - unique → has to be unambiguously distinguished
  - catchy → has to be recognized and memorized
  - associative → has to be intuitively associated to the solution
- **Description**
  - concise → has to be reasonably remembered
  - precise → has to be clear and unambiguous
  - normative → has to be foundational and stringent in expressiveness
- **Problem**
  - contextual → has to be described in a given context
  - regularly occurring → has to be motivated by enough situations
  - practically relevant → has to be motivated by enough practice
- **Solution**
  - general → has to be general enough to be sufficiently reusable
  - highly reusable → has to be applicable also in variants of the context
  - best practice → has to be considered a best or at least good practice

Pattern Rationale

ARCHITECTURE FUNDAMENTALS

Layer Architectures

(Patterns)

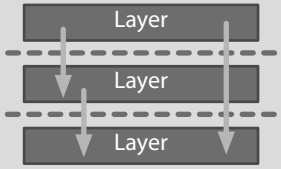
TECHNISCHE UNIVERSITÄT MÜNCHEN

AF 06.2

Layering Principle

Horizontally split code or data into two or more logically, optionally also spatially, clearly distinct, isolating, named, and ranked Layers.

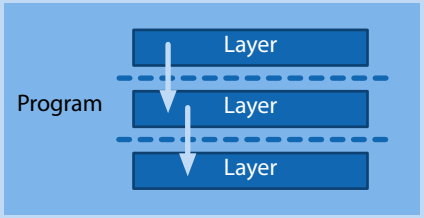
A Layer is not allowed to have relationships to or knowledge about any upper Layers. Additionally, for *Closed Layering,* each Layer is allowed to have relationships to and knowledge about the *directly* lower Layer only. In contrast to *Open Layering* or *Leaky Abstraction*, where each Layer is allowed to have relationships to and knowledge about *any* lower Layer.



LR Layer

Split related code or data of a Program into two or more logically distinct domain- or technology-induced Layers.

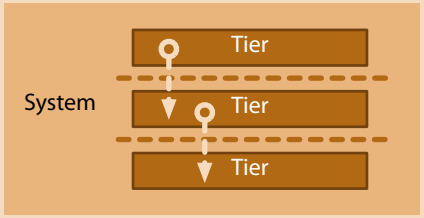
Rationale: Separation of Concern, Single Responsibility Principle, Mastering Complexity, Change Isolation, Functional Abstraction.



TR Tier

Split related code or data of a System into two, three or more logically and spatially distinct, network-connected, domain- or technology-induced Tiers.

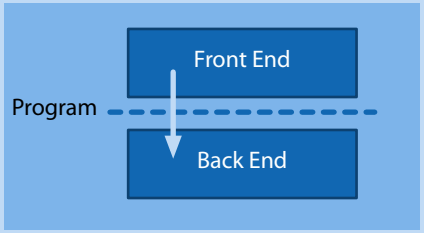
Rationale: Separation of Concern, Single Responsibility Principle, Mastering Complexity, Change Isolation, Functional Abstraction, Deployment Partitioning.



FB Front End / Back End

Split the code of a Program into exactly two logical Layers: a user-facing Front End and a data-facing Back End.

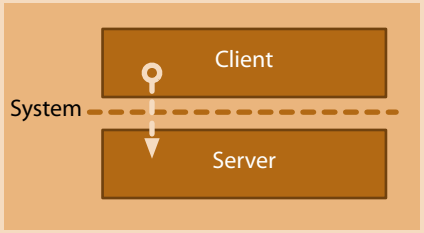
Rationale: Separation of Concern, Single Responsibility Principle, Mastering Complexity, Change Isolation, Functional Abstraction, Organisational Alignment.



CS Client / Server

Split the code of a System into two spatially distinct, network-connected Layers, each forming a stand-alone Program: a user-facing and multi-instantiated (Rich) Client and a data-facing (and logically) single-instantiated (Thin) Server. Both contain a Front/Back End.

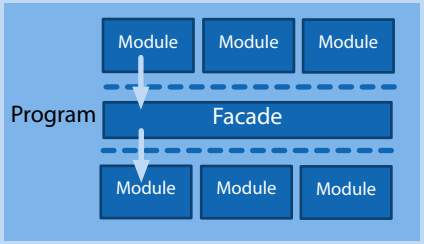
Rationale: Multi-User, User Computing Resource Leverage, Distributed Computing.



FD Facade

Splice a domain-specific Facade Layer into two Layers of two or more Modules. The extra Facade Layer acts as a broker between the Modules.

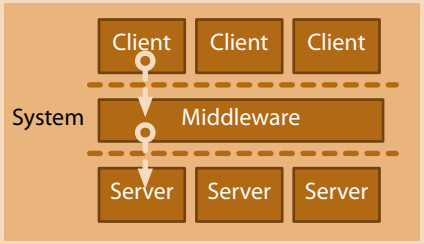
Rationale: Information Hiding, Cross-Cutting Concern Centralization, Functionality Orchestration, Authorization, Validation, Conversion.



MW Middleware

Splice a domain-unspecific Middleware Layer into a Client/Server communication. The extra Layer is a stand-alone Program Tier and acts as a broker between Client and Server.

Rationale: Communication Peer Discovery Simplification, Transport Protocol Conversions, Network Topology Flexibility.



ARCHITECTURE FUNDAMENTALS

Slice Architectures

(Patterns)

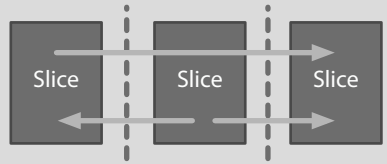
TECHNISCHE UNIVERSITÄT MÜNCHEN

AF 06.3

Slicing Principle

Vertically split code or data into two or more logically, optionally also spatially, clearly distinct, named, and unranked slices.

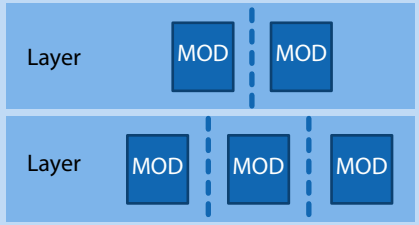
The particular slicing should minimize the total amount of individual relationships between the resulting slices. Per type of relationship, there should be no cycle in the transitive relationships.



MOD Concerned Module

Split related code or data (usually across a single Layer) into two or more logically distinct domain- or technology-induced Modules.

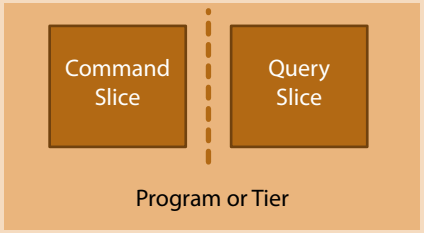
Rationale: Separation of Concern, Single Responsibility Principle, Mastering Complexity.



CQRS Command-Query Responsibility Segregation

Split code and data of a Program (across all Layers) or a Tier into exactly two slices to segregate operations that read data (queries) from the operations that update data (commands).

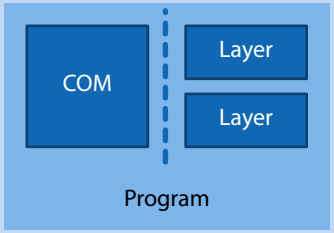
Rationale: Separated Scalability, Separated Data Access Patterns, Event Sourcing Approach.



COM Common Slice

Factor out common or cross concern code or data of a Program (across all Layers) into a single spatially distinct, separate slice.

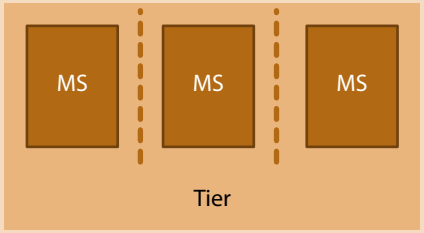
Rationale: Lack of Redundancy, Single Point of Truth, Reusability.



MS Microservice

Split code and data of a Tier (across all Layers) into two or more distinct, loosely-coupled, domain-enclosed, functional services, each forming a stand-alone Program.

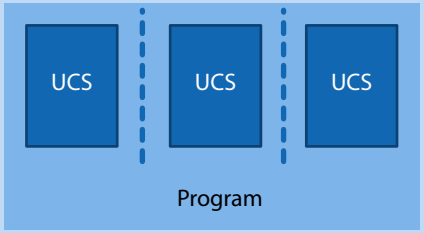
Rationale: Heterogeneity, Long-Term Large-Scale Maintenance, Replaceability, Resilience, (Scalability), (Easy Deployment), (Organizational Alignment), (Composability), (Reusability).



UCS Use-Case Slice

Split the code and data of a Program (across all Layers) into two or more purely logical slices, one for each distinct, domain-specific Use-Case.

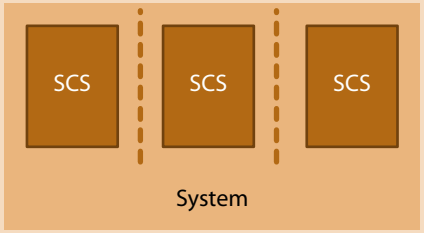
Rationale: Comprehensibility, Domain Alignment, Mastering Complexity.



SCS Self-Contained System

Split code and data of a System (across all Layers and Tiers) into two or more distinct, loosely-coupled, domain-enclosed, functional systems, each forming a stand-alone sub-System.

Rationale: Mastering Complexity, Heterogeneity, Resilience, Scalability, Easy Deployment, Organizational Alignment, Reusability, Replaceability.



ARCHITECTURE FUNDAMENTALS

Flow Architectures

(Patterns)

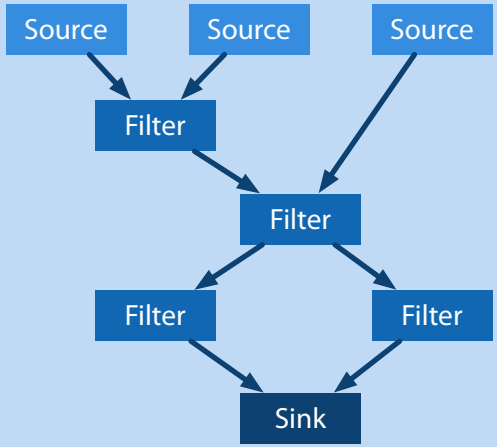
TECHNISCHE UNIVERSITÄT MÜNCHEN

AF 07.1

Pipes & Filters

Pass data through a directed graph of **Components** and connecting **Pipes**. The components can be **Sources**, where data is produced, **Filters**, where data is processed, or **Sinks**, where data is captured. Source and Filter components can have one or more output Pipes. Filter and Sink components can have one or more input Pipes. Components are independent processing units and operate fully asynchronously.

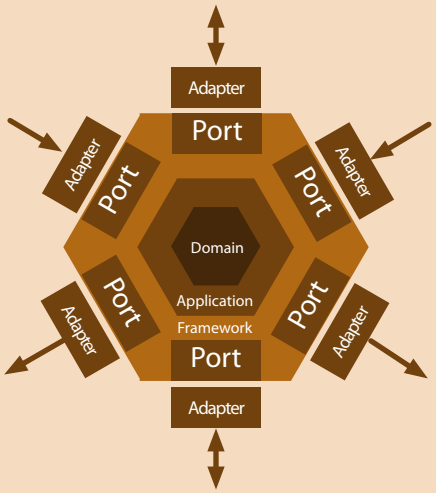
Examples: Unix commands with stdin/stdout/stderr and the Unix shell connecting them with pipes; Apache Spark or Apache Camel data stream processing pipelines.



Ports & Adapters (Hexagonal)

Perform communication in a Hub & Spoke fashion by structuring a solution into the three "Layers" **Domain**, **Application** and **Framework** and use the Framework layer to connect with the outside through **Ports** (general Interfaces) and **Adapters** (particular Implementations). Often some Ports & Adapters are user-facing sources and some are data-facing sinks, although the motivation for the Ports & Adapters architecture is to remove this distinction between user and data sides of a solution.

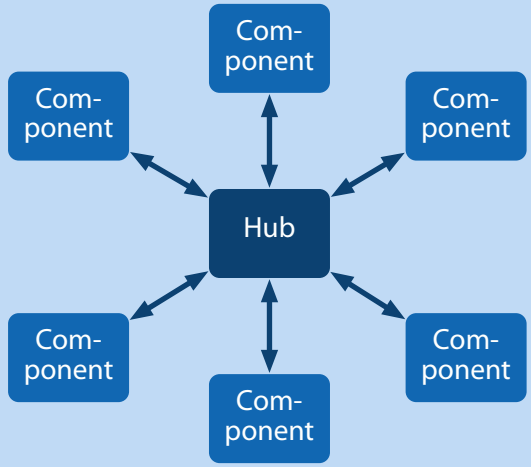
Examples: Message Queue, Enterprise Service Bus or Media Streaming Service internal realization.



Hub & Spoke

Perform communication (the **Spoke**) between multiple Components through a central **Hub** Component. Instead of having to communicate with N x (N-1) / 2 bi-directional interconnects between N Components, use the intermediate Hub to communicate with just N interconnects only. Sometimes one distinguishes between K (0 < K < N) source and N - K target Components and then K x (N - K) uni-directional interconnects are reduced to just N interconnects, too.

Examples: Message Queue, Enterprise Service Bus, Module Group Facade, GNU Compiler Collection, ImageMagick, etc.



ARCHITECTURE FUNDAMENTALS

Process Architectures

(Patterns)

TECHNISCHE UNIVERSITÄT MÜNCHEN

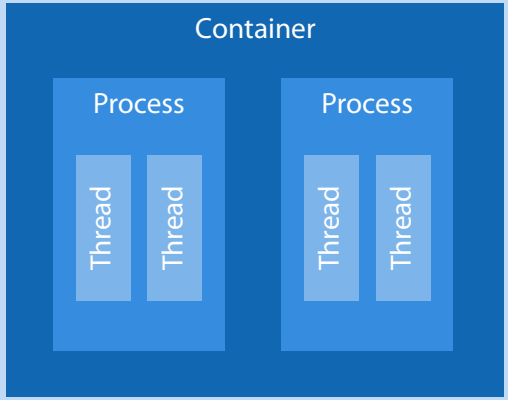
AF 07.2

Container, Process, Thread

The Operating System manages and orchestrates the run-time execution of applications in **Containers**, programs in **Processes** and control flows in **Threads**.

Containers are the ultimate enclosures, separating and controlling both the computing resources processor, memory, storage and network. Processes are the primary enclosures, still separating and controlling at least the computing resources processor and memory. Threads are the light-weight enclosures, just separating and controlling the computing resource processor. Containers can contain one or more Processes, and Processes can contain one or more Threads.

Examples: Docker Container, Unix Processes, POSIX Threads.

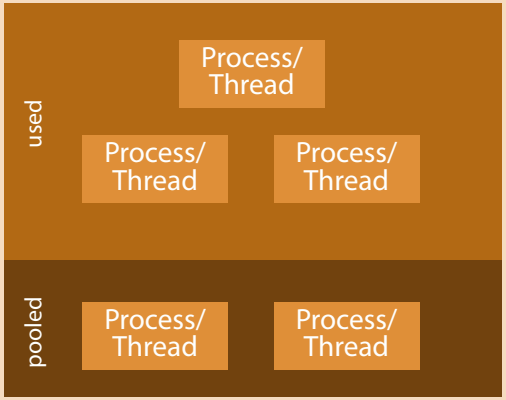


Process/Thread Pool

Instead of creating a Process/Thread for handling each incoming I/O request, pick a pre-created Process/Thread out of a resource **Pool** in order to increase performance and decouple I/O traffic (leading to threads of execution) from the actual computing resource usage and utilization.

The Process/Thread Pool usually has a lower and upper bound of processes/threads. The lower bound keeps the system "hot" between I/O requests. The upper bound limits the computing resource usage and avoids over-utilization.

Examples: Apache HTTP Daemon

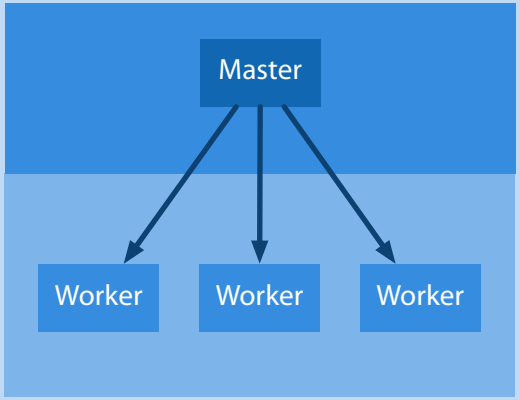


Master-Worker

The system has a single permanent **Master** container/process/thread and a Pool of many ephemeral **Worker** containers/processes/threads. The Master starts, restarts, pauses, resumes and stops the Workers and usually also delegates incoming I/O requests to them. The Workers process the I/O requests and deliver the responses.

Starting the Master usually implicitly starts an initial set of Workers (the initial Pool), stopping the Master implicitly stops all still pending Workers.

Examples: Unix init(8) daemon, Apache HTTP Daemon, SupervisorD, Node.js Cluster module



ARCHITECTURE FUNDAMENTALS

Cluster Architectures

(Patterns)

TECHNISCHE UNIVERSITÄT MÜNCHEN

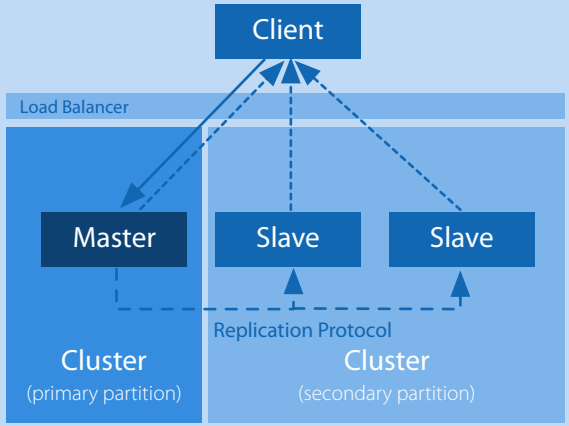
AF 07.3

Master-Slave (Static Replication)

Cluster of a single **Master** and multiple **Slave** nodes, where data is continuously copied from the Master to the Slave nodes in order to support high-availability (where a Slave will take over the Master role) in case of a Master outage and increased read performance (where regular read requests are also served by the Slaves).

In this static replication scenario the Master is usually assigned statically and in case of outages has to be reassigned usually semi-manually. Especially, the full reestablishment of the original Master assignment after a Master recovery usually is a manual process.

Examples: OpenLDAP Replication, PostgreSQL WAL Replication.

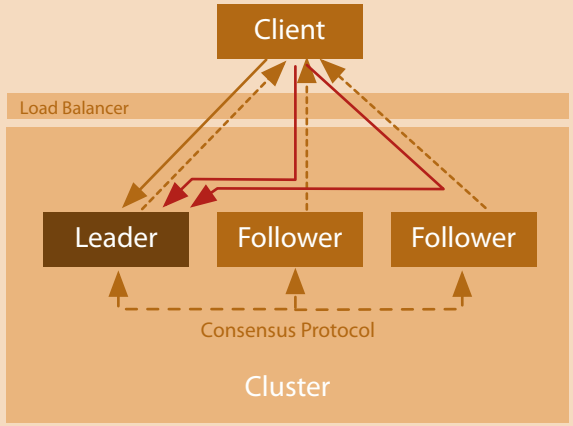


Leader-Follower (Dynamic Replication)

Cluster of a single **Leader** and multiple **Follower** nodes, where data is written on the current Leader node and data read on both the current Leader and all Follower nodes. For writing data to the cluster, the Leader node performs a consensus protocol (e.g. RAFT, Paxos or at least Two-Phase-Commit) with the Followers and this way automatically and consistently replicates the data to the Followers.

In this dynamic replication scenario the Leader is usually automatically assigned by the cluster nodes through an election protocol and in case of outages is automatically re-assigned. There is usually no re-establishment of the original Leader assignment.

Examples: Apache Zookeeper, Consul, EtcD, CockroachDB, InfluxDB.

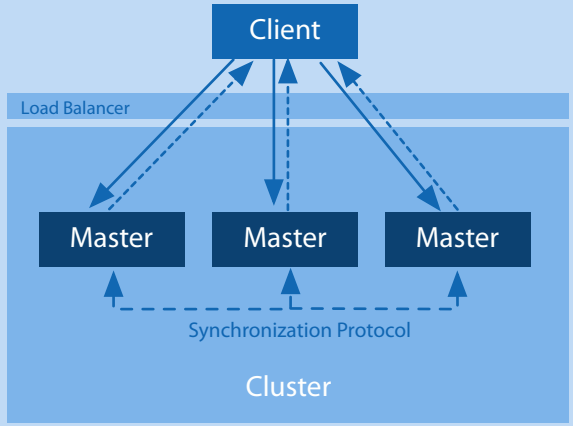


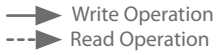
Master-Master (Synchronization)

Cluster of multiple **Master** nodes, where data is read and written on any Master node concurrently. The Master nodes either use Strict Consistency through writing to a mutual-exclusion-locked shared storage concurrently or use Eventual Consistency in a Shared Nothing storage scenario where they continuously synchronize their local data state to all other nodes with the help of a synchronization protocol.

The synchronization protocol usually is based on either Conflict-Free Replicated Data Types (CRDT) or at least Operational Transformation (OT). In any scenario, data update conflicts are explicitly avoided.

Examples: ORACLE RAC, MySQL/MariaDB Galera Cluster, Riak, Automerge/Hypermerge.





ARCHITECTURE FUNDAMENTALS

Networking Architectures

(Patterns)

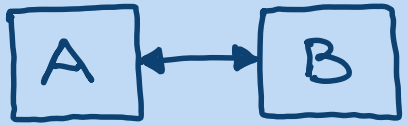
TECHNISCHE UNIVERSITÄT MÜNCHEN

AF 08.1

PTP Point-to-Point

Communicate between two network nodes in a point-to-point fashion, usually through a direct link.

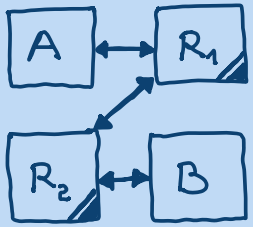
Rationale: simple communication where both nodes know about each other and can directly reach each other.



RTG Routing

Communicate between two network nodes in a point-to-point fashion, but by routing the network packets over intermediate forwarding nodes (routers).

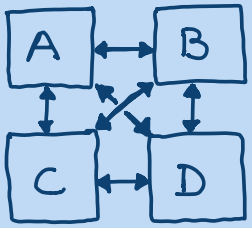
Rationale: simple communication where both nodes know about each other, but cannot directly reach each other.



P2P Peer-to-Peer

Communicate between multiple network nodes (usually all in the client and server role at the same time) without involving a central hub node (in the role of a server) — except for the initial network entry discovery.

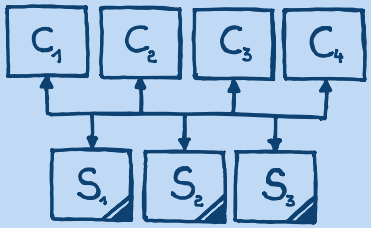
Rationale: communication without central control (although a seed peer is required).



C/S Client/Server

Communicate between multiple nodes in the client role (making requests, and usually with ephemeral addresses) and multiple nodes in the server role (serving responses, and usually with fixed addresses).

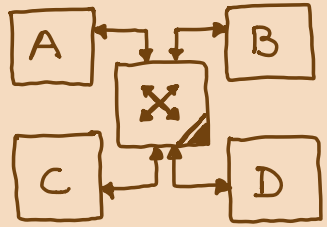
Rationale: communication with central orchestration, control and data storage.



BUS Bus/Broker/Relay

Communicate between multiple nodes with the help of a central packet forwarding hub node in a star network topology.

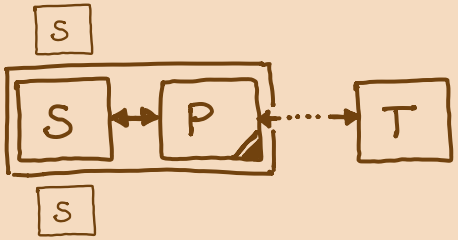
Rationale: decouple communication nodes: instead of Point-to-Point (PTP) communications between all nodes, there are just PTP communications with the hub.



FPR (Forward) Proxy

Communicate between two nodes by using an intermediate forwarding proxy node in front of the source node.

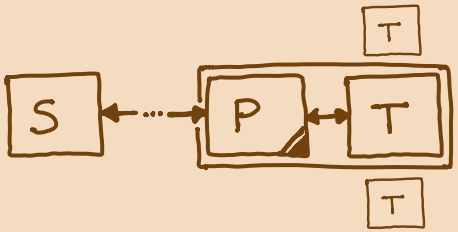
Rationale: bridge network topology constraints (segmented networks); caching at source side; auditing of communication.



RPR Reverse Proxy

Communicate between a source and a target node by using a masquerading proxy node directly in front of the target node.

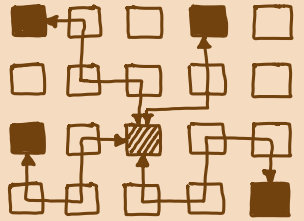
Rationale: load balancing for multiple target nodes; caching at target side; auditing of communication; security shielding of target nodes; protocol conversions.



VPN Virtual (Private) Network

Communicate between nodes in a logical star network topology on top of an arbitrary physical routed network topology.

Rationale: secure private network overlaying an unsecure public network; simplify network topology.



ARCHITECTURE FUNDAMENTALS

Communication Architectures

(Patterns)

TECHNISCHE UNIVERSITÄT MÜNCHEN

AF 08.2

UCT Unicast (one-to-one)

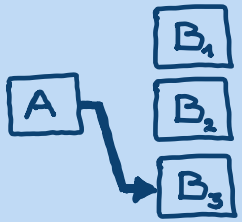
Communicate messages from one source to exactly one destination node. The destination node is explicitly and individually addressed.

Rationale: private communication between exactly two nodes which both know each other beforehand.

ACT Anycast (one-to-any)

Communicate messages from one source to one of many destination nodes. The picked destination node usually is the network-topology-wise "nearest" or least utilized node in a group of nodes.

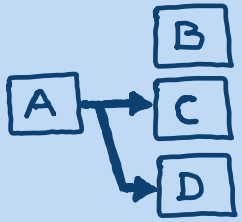
Rationale: Unicast, optimized for network failover scenarios, load balancing and CDNs.



MCT Multicast (one-to-many)

Communicate messages from one source to many destination nodes. The destination nodes usually form a group and are usually not individually addressed.

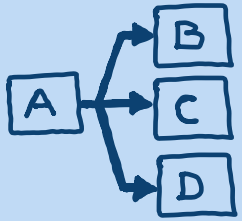
Rationale: node communication where destination nodes dynamically change or where total traffic should be reduced.



BCT Broadcast (one-to-all)

Communicate messages from one source to all available destination nodes. The destination nodes usually are implicitly defined by the extend of the local communication network segment.

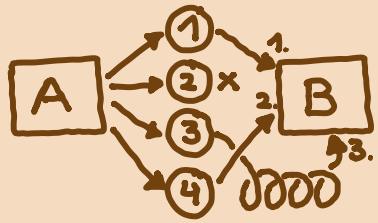
Rationale: spreading out messages to all available nodes for potential responses.



DGR Datagram (Single Packet)

Communicate messages as an unordered set of single packets, usually without any network congestion control, retries or other delivery guarantees.

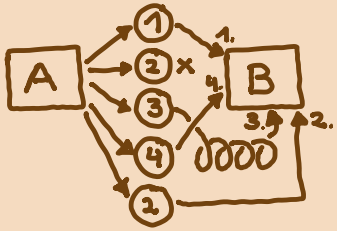
Rationale: simple low-overhead communication without prior communication establishment (handshake).



STR Stream (Sequence of Packets)

Communicate messages as an ordered sequence (stream) of packets, usually with network congestion control, retries and delivery guarantees (at-most-once, exactly-once, at-least-once).

Rationale: reliable communication between nodes.



PLL Pull (Request/Response, RPC)

Communicate by performing a request (from the client node) and pulling a corresponding response (from the server node).

Rationale: Remote Procedure Call (RPC) like Unicast or Anycast communication.

PSH Push (Publish/Subscribe, Events)

Communicate by "subscribing" to "channels" of messages (on one or more receiver nodes or on an intermediate hub) once and then publishing events to those "channels" (on the sender node) multiple times.

Rationale: event-based Multicast or Broadcast communication.