Curs 13

Distributed Computing Patterns

Distributed systems

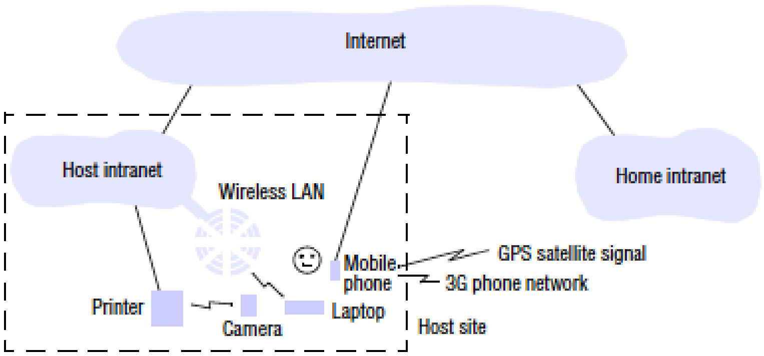
- Un sistem distribuit poate fi definit ca fiind format din **componente hardware si software localizate intr-o retea de calculatoare care comunica si isi coordoneaza actiunile doar bazat pe transmitere de mesaje.**
- Calcul distribuit (Distributed-Computing) = rezolvarea unor probleme folosind sisteme distribuite

Tendinte

Influente semnificative:

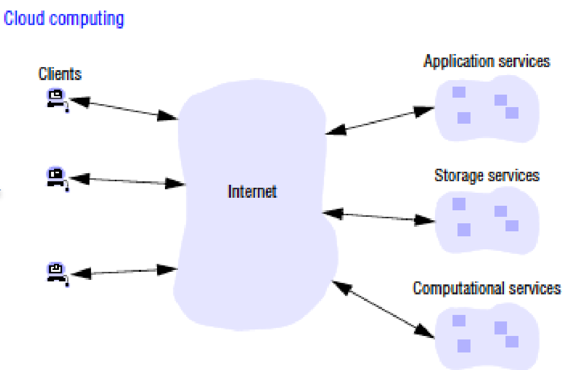
- emergenta tehnologiilor de retea de scara larga

- emergenta necesitatilor crescute de calcul cuplata cu dorinta de asigura suport pentru mobilitatea utilizatorilor



- cresterea cererii de servicii multimedia

- perspectiva asupra sistemelor distribuite ca fiind o utilitate publica



Caracteristici

Concurenta:

- ***se lucreaza cu programe care se executa concurent si care partajeaza resurse***

No global clock:

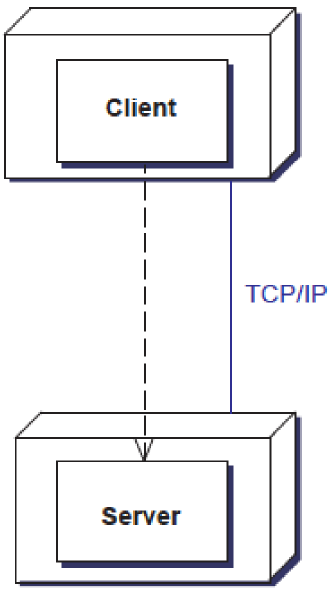
- ***nu exista notiunea de timp global***
- aceasta este o consecinta directa a faptului ca singura modalitate de comunicare este transmiterea de mesaje printr-o retea

Independent failures:

Fiecare componenta a sistemului poate 'cadea' in mod independent lasand celelalte in starea de executie ('run').

- toate retelele de calculatoare pot esua('fail') si este responsabilitatea proiectantilor sistemului sa gestioneze efectele in aceste cazuri si sa asigure masuri de reorganizare.
- Aceste tipuri de probleme conduc la izolarea computerelor conectate prin aceste retele aflate in starea de 'fault' – dar nu inseamna si oprirea celorlalte computere;
- Programele pot sa continue sa functioneze dar nu pot detecta daca reteaua a cazut sau este doar incetinita.
- Similar, 'caderea' unui computer, sau oprirea neasteptata a unui software undeva in sistem (*a crash*), nu este imediat facuta cunoscuta celorlalte componente cu care acesta comunica

Client-Server pattern



- O componenta de tip server care furnizeaza servicii catre mai multe complemente client.
- O componenta client cere servicii de la componenta server.
- Serverele sunt active permanent 'ascultand' cererile de la clienti.

Starea(State) in sablonul Client-server

Clientii si serverele lucreaza in general in sesiuni (‘sessions’).

–**stateless server --** starea unei sesiuni (session state) este gestionata de catre client. Aceasta stare (client) este trimisa impreuna cu fiecare cerere. In aplicatiile web, *session state* poate fi stocata ca si parametrii URL, in campuri ascunse sau folosind cookies (obligatoriu pentru arhitecturile REST folosite pentru aplicatii web).

–**stateful server --** starea unei sesiuni (session state) este mentinuta la nivel de server si este asociata cu ID clientului

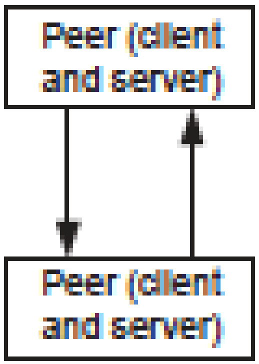
Modalitatea de gestionare a starii unei sesiuni influenteaza tranzactiile, scalabilitatea si gestiunea erorilor (*fault handling*).

- Tranzactiile trebuie sa fie
  - atomice si sa asigure consistenta starii,
  - izolate (sa nu afecteze alte tranzactii)
  - durabile
- *fault handling* => starea mentinuta la nivelul clientului implica faptul ca toata informatia se va pierde in cazul in care clientul esueaza (*fails*).
- Securitatea poate fi afectata daca starea se mentine la nivel de client pentru ca informatia se transmite de fiecare data (la fiecare *request*).
- Scalabilitea poate fi redusa daca starea se mentine la nivelul serverului ‘*in-memory*’ – multi client, multe cereri => necesar de memorie crescut.

Peer-to-peer pattern

- Poate fi privit ca si un sablon Client-Server **simetric**:
  - un nod (*peer*) poate functiona ca si un client – care cere servicii de la alte componente sau ca si server care furnizeaza servicii pentru altii.
  - rolul unui nod se poate schimba in mod dinamic
- Atat clientii cat si servere folosesc in mod uzual multithreading.
- Serviciile pot fi implicite (de exemplu prin intermediul unui stream de conectare) in locul unei cereri (request) trimise prin invocare directa.
- Un *peer* care actioneaza ca si server isi poate informa colegii (peers) care activeaza ca si clienti de aparitia unor evenimente; clientii pot fi informatii folosind de exemplu o magistrala de evenimente (event-bus).

Exemple



- the distributed search engine Sciencenet,
- multi-user applications like a drawing board,
- peer-to-peer file-sharing like Gnutella or Bittorrent.

Caracteristici

- **Performanta** creste atunci cand numarul de noduri creste dar scade atunci cand sunt prea putine

Avantaje

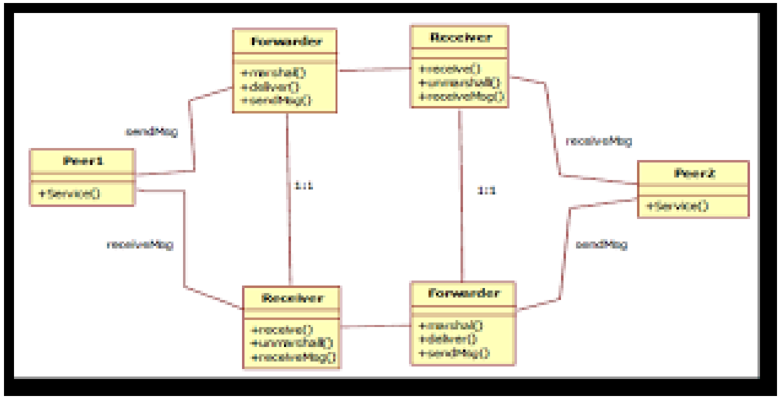
- Nodurile pot folosi capacitatea intregului sistem chiar daca fiecare are o capacitate proprie limitata.
  - este un **cost individual mic cu beneficiu mare** obtinut prin partajare
- Overhead-ul de administrare este scazut pentru ca retelele peer-to-peer se organizeaza intern (self-organizing)
- Asigura **scalabilitate** foarte buna si este rezilienta la esec/caderea(failure) componentelor individuale.
- Configurarea sistemului se poate schimba **dinamic**: un *peer* poate intra sau pleca in timp ce sistemul functioneaza.

Dezavantaje

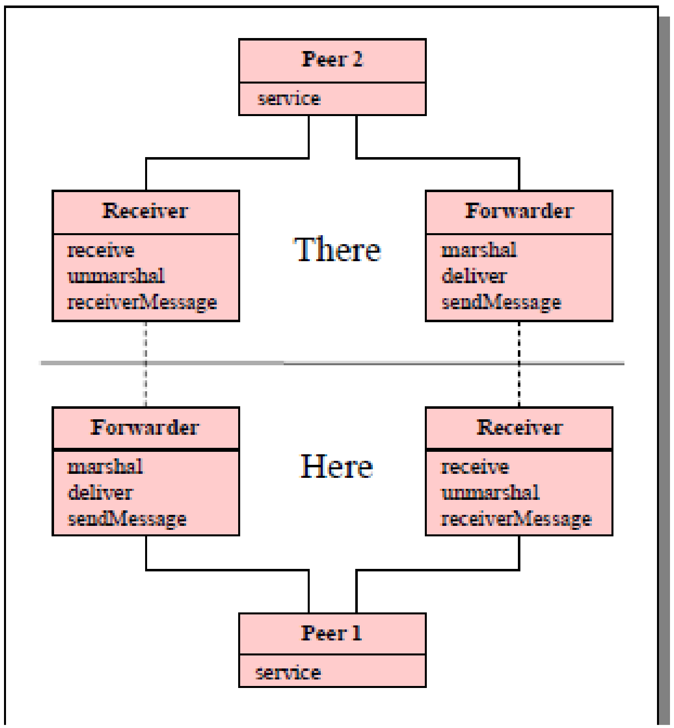
- nu exista garantia calitatii serviciilor (***no guarantee about quality of service)*** deoarece nodurile coopereaza voluntar
- nu exista garantia securitatii (***security is difficult to guarantee)*** deoarece nodurile coopereaza voluntar

Forwarder-Receiver

- **Communication Pattern**
  - Forwarder-Receiver furnizeaza in mod transparent comunicarea inter-proces pentru sistemele sistem cu model de interactiune de tip peer-to-peer.
  - Foloseste *forwarders* si *receivers* pentru a decupla nodurile de mecanismul de comunicare de baza (the underlying mechanism).
  - *Forwarders* sunt responsabili pentru transmiterea de mesaje folosind mecanisme specifice IPC (Inter Process Communication)
  - *Receivers* sunt responsabili pentru receptionarea IPC requests sau mesaje trimise de catre alti peers folosind mecanisme IPC si pentru apelarea metodelor corespunzatoare.



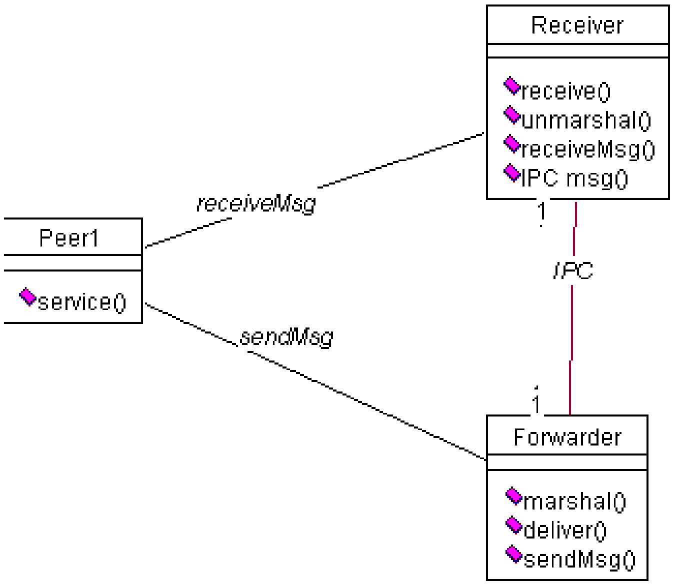
Forwarder-Receiver



- The details of the underlying IPC mechanism for sending or receiving messages are hidden from the peers by encapsulating all system-specific functionality into separate components.
- Examples of such functionality are
  - the mapping of names to physical locations,
  - the establishment of communication channels, or
  - the marshaling and unmarshaling of messages (marshalling = producing a stream of byte which contain enough information to be able to re-build the object)

F-R - types of messages

- *Command message*- instruct the recipient to perform some activities.
- *Information message*- contain data.
- *Response message*- allow agents to acknowledge the arrival of a message.
  - It includes functionality for sending and marshaling



Forwarder-Receiver

- Peer components are responsible for application tasks.
- Peers may be located on a different process, or even on a different machine.
  - It uses a forwarder to send messages to other peers and a receiver to receive messages form other peers.
  - They continuously monitor network events and resources, and listen for incoming messages form remote agents.
  - Each agent may connect to any other agent to exchange information and requests.
  - To send a message to remote peer, it invokes the method `sendmsg` of its forwarder.
  - It uses `marshal.sendmsg` to convert messages that IPC understands.
  - To receive it invokes `receivemsg` method of its receiver to unmarshal it uses `unmarshal.receivemsg`.
  - Forwarder components send messages across peers.
  - When a forwarder sends a message to a remote peer, it determines the physical location of the recipient by using its name-to-address mapping.
  - Receiver components are responsible for receiving messages.
    - It includes functionality for receiving and unmarshaling messages.

F_R Dynamics

- P1 requests a service from a remote peer P2.
- It sends the request to its forwarder forw1 and specifies the name of the recipient.
- forw1 determines the physical location of the remote peer and marshals the message.
- forw1 delivers the message to the remote receiver recv2.

At some earlier time P2 has requested its receiver recv2 to wait for an incoming requests.

- recv2 receives the message arriving from forw1.
- recv2 unmarshals the message and forwards it to its peer P2.
- Meanwhile P1 calls its receiver recv1 to wait for a response.
- P2 performs the requested service and sends the result and the name of the recipient P1 to the forwarder forw2.
- The forwarder marshals the result and delivers it recv1.
- Recv1 receives the response from P2, unmarshals it and delivers it to P1.

Architectural patterns

Frank Buschmann. Kevlin Henney.Douglas C. Schmidt. ***Pattern-Oriented Software Architecture,*** Volume 4:

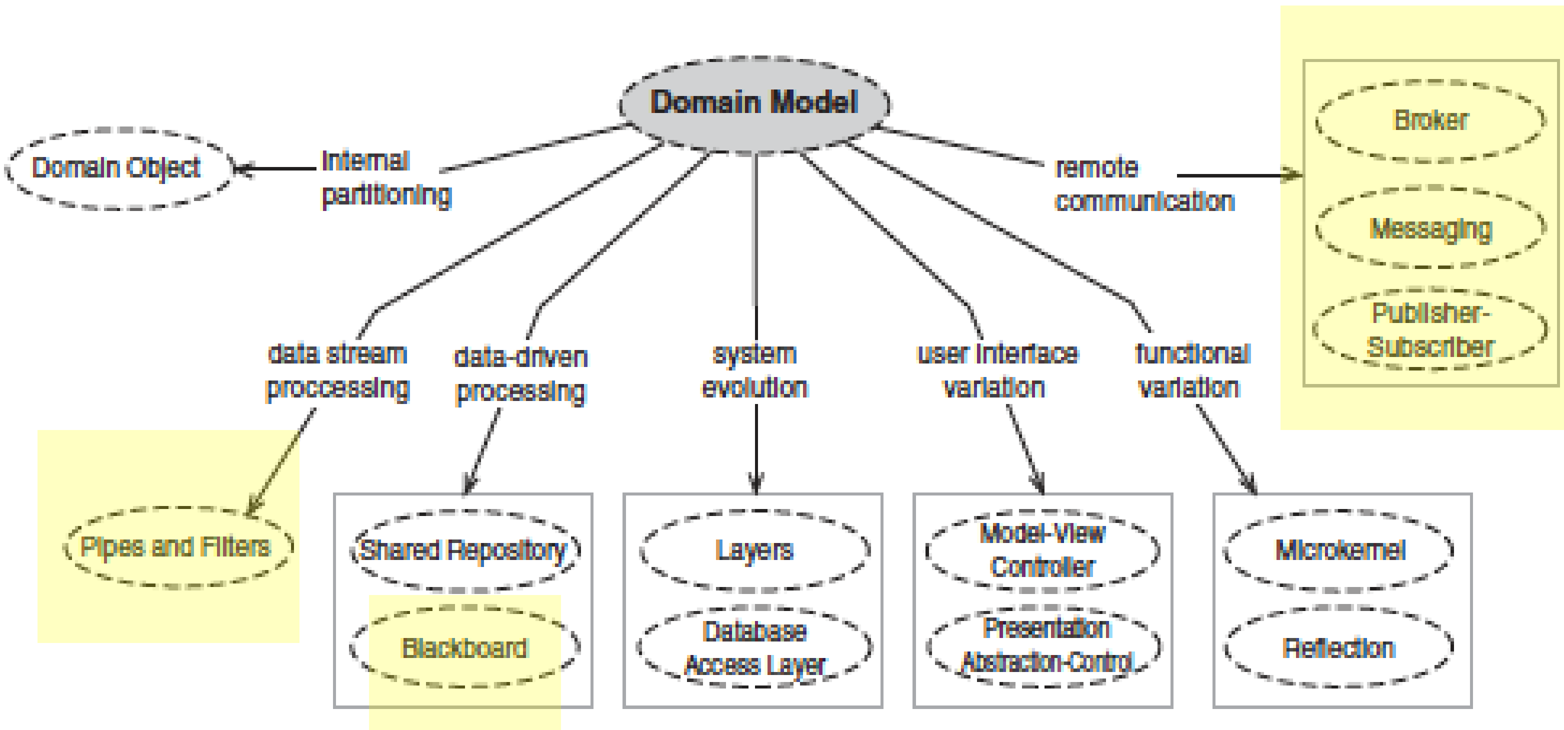
A Pattern Language for Distributed-Computing. Wiley & Sons, 2007

Un sablon arhitectural este un concept care

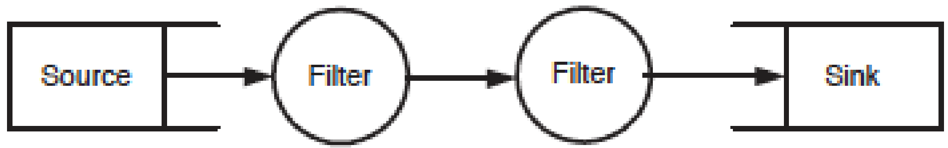
rezolva si delimiteaza anumite elemente esentiale de coeziune ale unei arhitecturi software.

- Domain Model
- Layers
- Model-View-Controller
- Presentation-Abstraction-Control
- Microkernel
- Reflection
- Pipes and Filters
- Shared Repository
- Blackboard
- Domain Object

Conexiunea cu Domain Layer

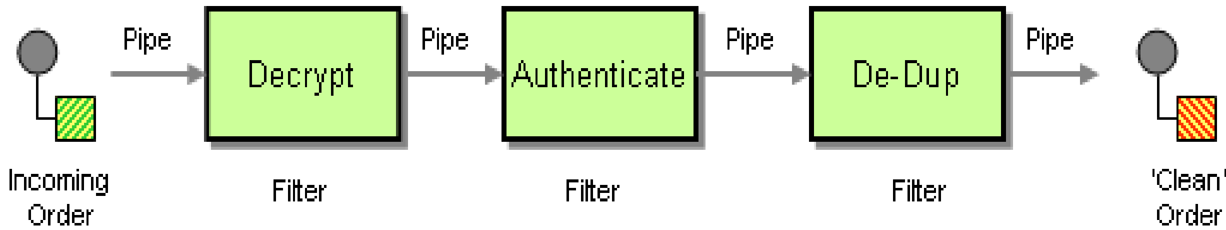


Pipe-Filter Pattern



- furnizeaza pentru un sistem o structura care produce un ***stream de date***
- fiecare pas de procesare este incapsulat intr-o componenta de tip *filter*
- Datele sunt transferate prin pipes
  - *pipe* – leaga 2 filtre
  - *pipes* pot fi utilizate pentru sincronizare sau pentru buffering

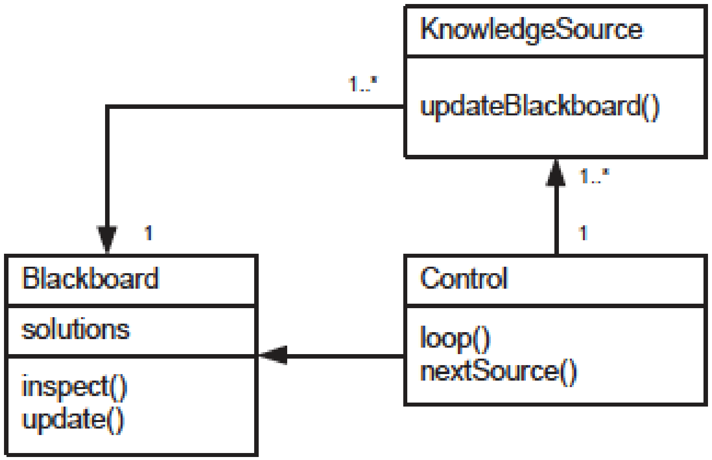
Exemplu



- se poate utiliza pentru a divide taskuri de procesare mari intr-o secventa de componente independente mai mici de procesare (Filters) care sunt conectate prin canale (Pipes).
- fiecare filtru expune o interfata simpla – primeste mesaje de la *inbound pipe,* proceseaza mesajul si publica rezultatul la outbound pipe.
- pentru ca toate componentele utilizeaza aceeasi interfata externa ele pot fi compuse in diferite solutii prin conectarea componentelor la pipe-uri diferite
- se pot adauga filtre sau rearanja in secvente noi fara a se schimba filtrele (in interior).

Blackboard Pattern

arata cum se poate rezolva o problema complexa precum recunoasterea de imagini sau de limbaj prin impartirea in subsisteme mai mici specializate care pot rezolva problema impreuna.



- mai multe subsisteme specializate asambleaza cunostinte pentru a construi partial sau aproximativ solutia
- ***Toate componentele au acces la ansamblul de datele partajate = the blackboard.***
- Componentele pot produce date noi care sunt adaugate pe blackboard.
- Componentele cauta anumite date pe blackboard, folosind e.g. pattern matching.

Componente

- Class
  - **Blackboard**
- Responsibility
  - Manages central data
- Collaborators
  - no

- Class
  - **Knowledge Source**
- Responsibility
  - Evaluates its own applicability
  - Computes a result
  - Updates Blackboard
- Collaborators
  - Blackboard

- Class
  - **Control**
- Responsibility
  - Monitors Blackboard
  - Schedules knowledge source activations
- Collaborators
  - Blackboard
  - Knowledge Source

Descriere generala

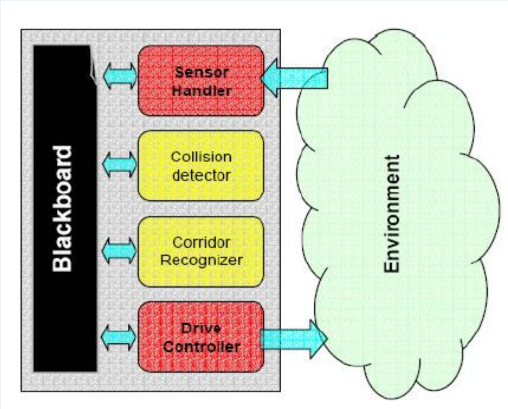
- Blackboard permite mai multor procese (agenti) sa comunice prin citirea si scrierea de cereri si informatii catre un depozit de date globale.
- **Fiecare agent participant are o expertiza in propriul domeniu**, si are un anumit tip de cunoastere referitoare la rezolvarea problemei (knowledge source) care se poate aplica la o parte a problemei, i.e., problema nu se poate rezolva de catre un singur agent.
- **Agentii communica strict prin intermediul unei *common blackboard*** care este vizibil tuturor agentilor.
- Atunci cand o problema partiala trebuie rezolvata potentialii agenti care ar putea sa o rezolve sunt listati.
- O **unitate de control** este responsabila pentru selectarea agentilor si atribuirea de sarcini acestora.

Exemplu: speech recognition

Ciclul principal de rezolvare

- **Control** calls **nextSource()** to select the next knowledge source
- **nextSource()** looks at the blackboard and determines which knowledge sources to call
- For example, **nextSource()** determine that **Segmentation, Syllable Creation** and **Word Creation** are candidate
- **nextsource()** invokes the **condition-part** of each candidate knowledge source
- The **condition-parts** of candidate knowledge source inspect the blackboard to determine if and how they can contribute to the current state of the solution
- The **Control** chooses a knowledge source to invoke and a **set of hypotheses** to be worked on (according to the result of the condition parts and/or control data)
- Apply the **action-part** of the knowledge source to the **hypothesis**
- ***New contents are updated in the blackboard***

Robot example



- An Experimental robot is equipped with four agents:
  - Sensor Handler Agent,
  - Collision Detector Agent,
  - Corridor Recognizer Agent and
  - Drive Controller Agent

(Includes the control software)

- Agents and blackboard form the control system. Agent cooperation is reached by means of the blackboard. Blackboard is used as a central repository for all shared information.
- Only two agents have an access to the environment: Sensor Handler Agent and Drive Controller Agent.
- There is no global controller for all of these agents, so each of them independently tries to make a contribution to the system during the course of navigation.
- Basically each of the four agents executes its tasks independently using information on the blackboard and posts any result back to the blackboard.

Avantaje & Dezavantaje

- Avantaje
  - potrivit pentru diverse surse de date/procesare
  - potrivit pentru medii distribuite
  - **potrivit pentru planificarea taskurilor si a deciziilor**
  - **potrivit pentru abordari de rezolvare in echipa** – se posteaza subcomponente si rezultate partiale
  - util pentru probleme pentru care nu sunt cunoscute strategii de rezolvare deterministe => opportunistic problem solving.
- Dezavantaje
  - Scump
  - Dificil de a determina partitionarea pentru knowledge
  - Control unit poate fi foarte complexa

….patterns legate de infrastructura de comunicare

- **Messaging**
  – Distribution Infrastructure
- **Publisher-Subscriber**
  – Distribution Infrastructure
- **Broker**
  – Distribution Infrastructure
- **Client Proxy**
  – Distribution Infrastructure
- **Reactor**
  – Event Demultiplexing and Dispatching
- **Proactor**
  – Event Demultiplexing and Dispatching

Messaging Pattern

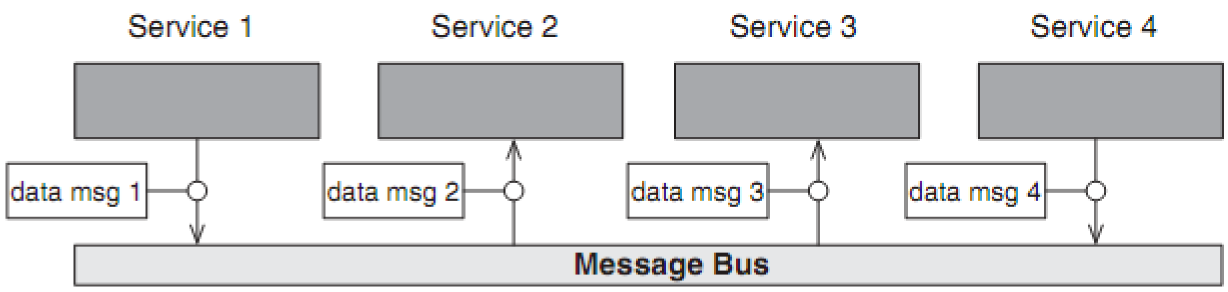
- Unele sisteme distribuite sunt compuse din servicii care sunt dezvoltate independent.

- Pentru a forma un sistem coerent aceste servicii trebuie sa interactioneze intr-un mod fiabil fara a implica totusi o dependenta stransa intre ele.

- **Solutie:** Conectarea printr-un canal de mesaje *(a message bus)* care sa permita transferul de date ***asincron.***
  - mesajele se codifica astfel incat comunicarea sa se poata face fara sa fie nevoie de sa fie cunoscute toate informatiile legate de tipurile de date.

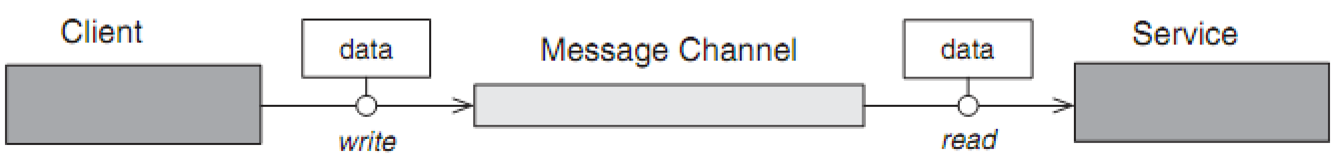
Messaging

- Message-based communication suporta ***loose coupling***



- *Mesajele* contin doar datele care pot fi interschimbate intre setul de clienti si servicii – nu si cine este interesat de acestea.

=> conectarea clientilor si serviciilor printr-un canal care permite schimbul de mesaje “Message Channel”.



Publisher-Subscriber Pattern

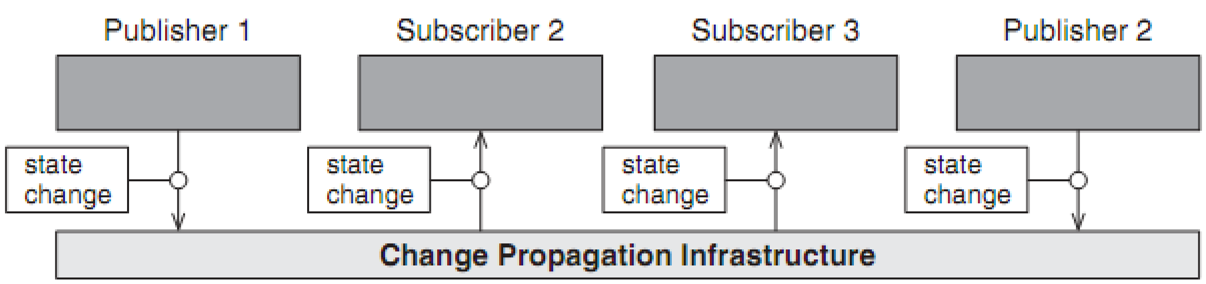
- Componentele din anumite aplicatii distribuite sunt cuplate slab si opereaza in general independent.

- pentru a propaga informatii in asemenea aplicatii se poate folosi un mechanism de notificare prin care sa se faca informari referitoare la modificari de stare sau referitoare la aparitia unor evenimente.

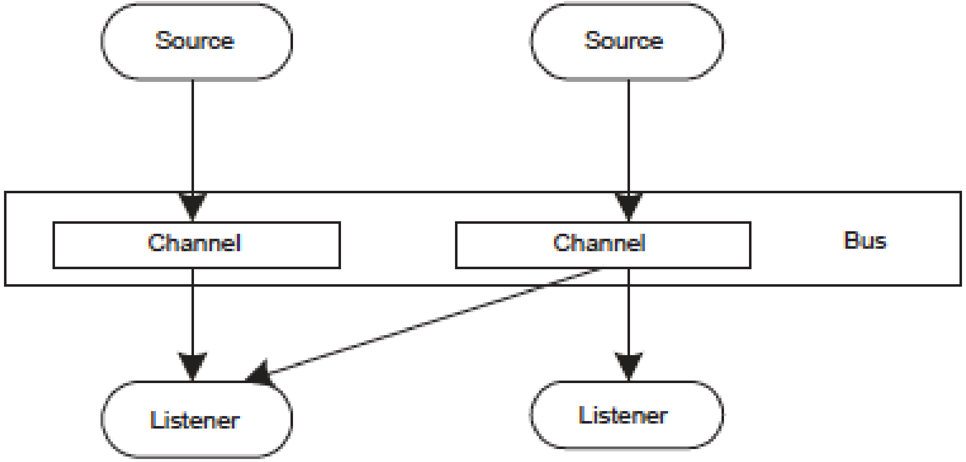
- **<u>Solutie</u>:** Definerea unei infrastructuri de propagare a informatiei care permite editorilor sa disemineze evenimente care contin informatie care ar putea sa intereseze alti actori.
  - se notifica abonatii inregistrati pentru a primi anumite tipuri de notificari

Publisher-Subscriber

- Editorii inregistreaza ce tipuri de evenimente publica.
- Abonatii inregistreaza de ce tipuri de evenimente sunt interesati.
- Infrastructura foloseste informatiile inregistrate pentru a transmite prin retea evenimentele de la editori la abonatii inregistrati a fi interesati.



Event-Bus Pattern



- Sursele de evenimente (*Event sources*) publica mesaje pe canale particulare pe un (*event bus)*
- Event listeners se aboneaza la anumite canale.
- Listenerii sunt notificati referitor la canalele care sunt publicate pe un canal la care s-au abonat.
- Generarea si notificarea de mesaje este **asincrona** :
  - un event source genereaza un mesaj – nu asteapta ca acesta sa fie primit de catre listeneri

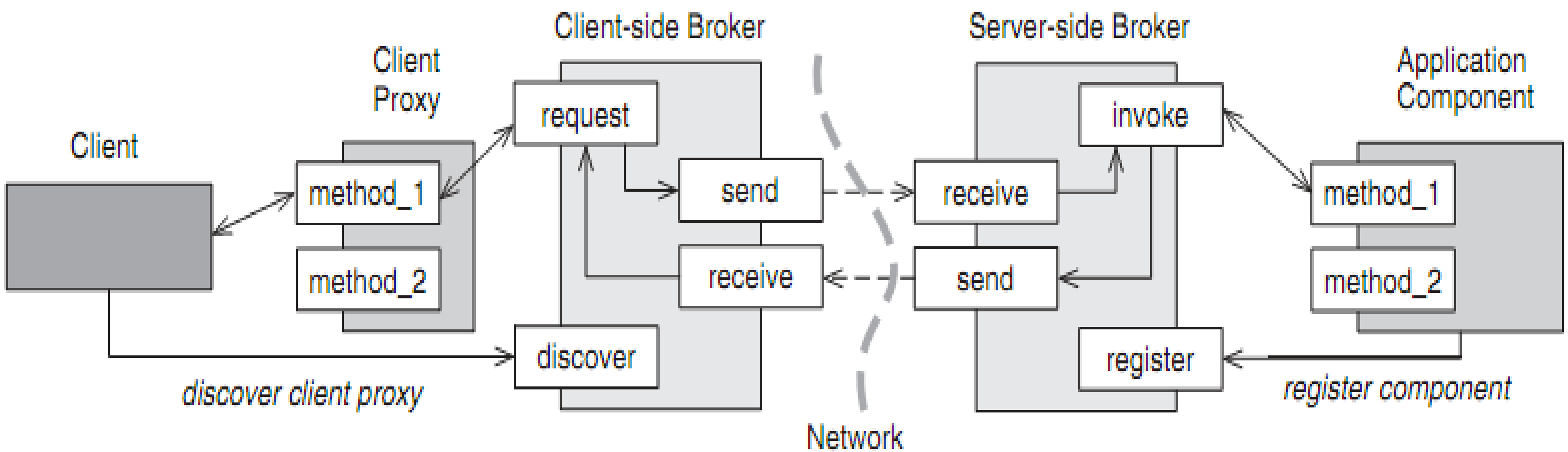
Broker Pattern

- Sistemele distribuite pot avea dificultati (provocari) care nu apar in sistemele cu un proces
  - Important – codul aplicatiile nu trebuie sa trateze aceste probleme in mod direct => intermediari (brokers)
- aplicatiile trebuie simplificate prin modularizare ***modular programming model*** care poate ascunde detaliile de retea si locatie

- **Solutie:** Folosirea unei federatii de brokeri
  - ***brokers to separate and encapsulate the details of the communication infrastructure*** in a distributed system **from its application functionality**.

- Definirea unui model de tip ***component-based programming model prin care clientii sa poate sa invoce metode sau servicii remote ca si cum ar fi locale***

Broker



Client-side Broker
Server-side Broker
Client
Proxy
Application
Component
Client
request
invoke
method_1
send
receive
method_1
method_2
receive
send
method_2
discover
register
discover client proxy
register component
Network

- .

Client-Proxy Pattern

- Atunci cand se construieste o infrastructura de tip broker *client-side* pentru o componenta *remote* trebuie sa se asigure o abstractizare care permite clientilor sa acceseze acele componente folosind ***remote method invocation***.

- un "Client Proxy / Remote Proxy" reprezinta o componenta remote- in the spatial de adrese al clientului.
- Proxy ofera o interfata identica care mapeaza invocarile de metode specifice catre functionalitatea orientate catre transmiterea de mesaje ale brokerului.

- ***Proxies allow clients to access remote component functionality as if they were collocated.***

Event Demultiplexing & Dispatching

- At its heart, distributed computing is all about ***handling and responding to events*** received from the network.

- There are patterns that describe different approaches for initiating, receiving, demultiplexing, dispatching, and processing events in distributed and networked systems.

- …two of these patterns:
  - Reactor ... synchronous
  - Proactor ... asynchronous

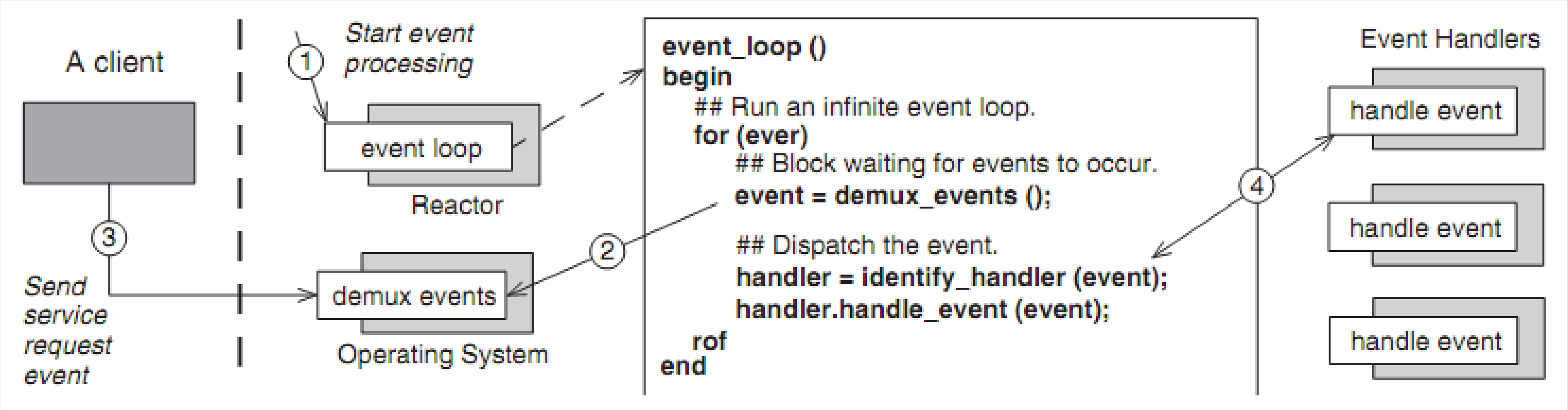
Reactor Pattern

- Event-driven software often
  - receives service request events from multiple event sources, which it demultiplexes and dispatches to event handlers that perform further service processing.

- Events can also arrive simultaneously at the event-driven application.
  - To simplify software development, events should be processed sequentially | synchronously.

Reactor

- **<u>Solution</u>:** *Provide an event handling infrastructure that waits on multiple event sources simultaneously for service request events to occur, but only demultiplexes and dispatches* ***one event at a time*** *to a corresponding event handler that performs the service.*



- It defines an event loop that uses an operating system event demultiplexer to wait **<u>synchronously</u>** for service request events.
- By ***delegating the demultiplexing of events to the operating system***, the reactor can wait for multiple event sources simultaneously without a need to multi-thread the application code.

Proactor Pattern

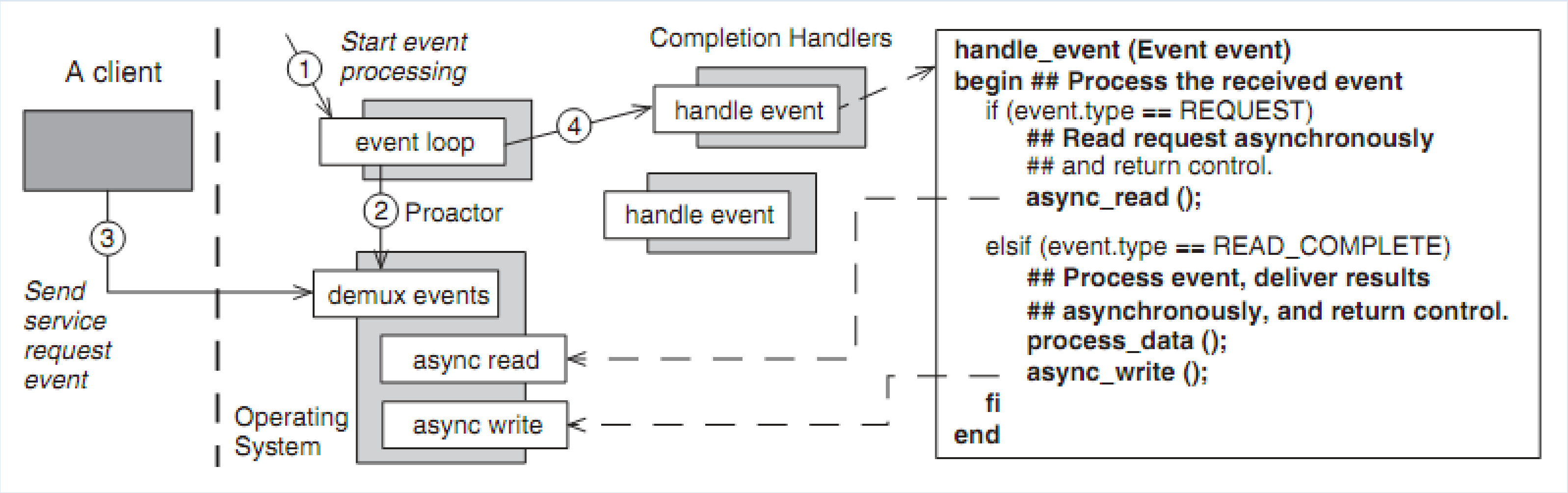
- To achieve the required performance and throughput, event-driven applications must often be able ***to process multiple events simultaneously***.

- However, **resolving this problem via multi-threading, may be undesirable, due to the overhead of synchronization, context switching and data movement**.

- **<u>Solution</u>:**
  - ***Split an application's functionality into***
    - ***asynchronous operations*** that perform activities on event sources and
    - **completion handlers** that ***use the results of asynchronous operations to implement application service logic***.
  - Let the operating system execute the asynchronous operations, but
  - execute *the completion handlers in the application's thread of control*.

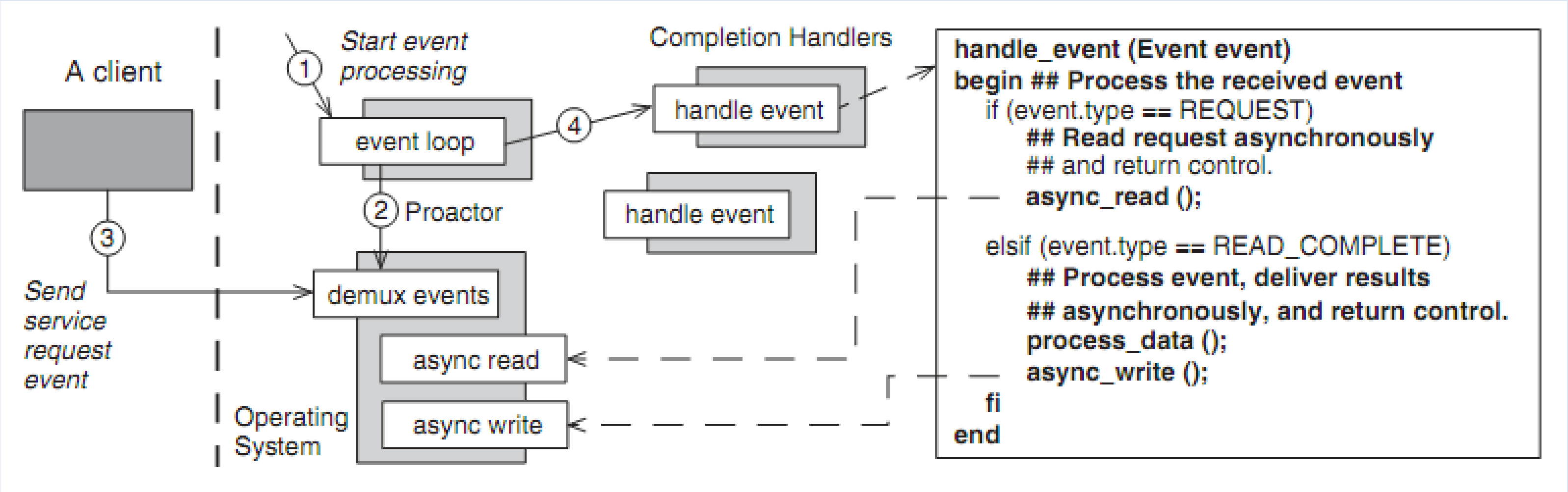
Proactor

- *A proactor component coordinates the collaboration between completion handlers and the operating system.*
  - It defines an event loop that uses an operating system event demultiplexer to wait synchronously for events that indicate the completion of asynchronous operations to occur.



- Initially **all completion handlers 'proactively' call an asynchronous operation to wait for service request events to arrive,** and then run the event loop on the proactor.

Proactor



- When such an event arrives, the proactor dispatches the result of the completed asynchronous operation to the corresponding completion handler.
- This handler then continues its execution, which may invoke another asynchronous operation.

Reactor vs. Proactor

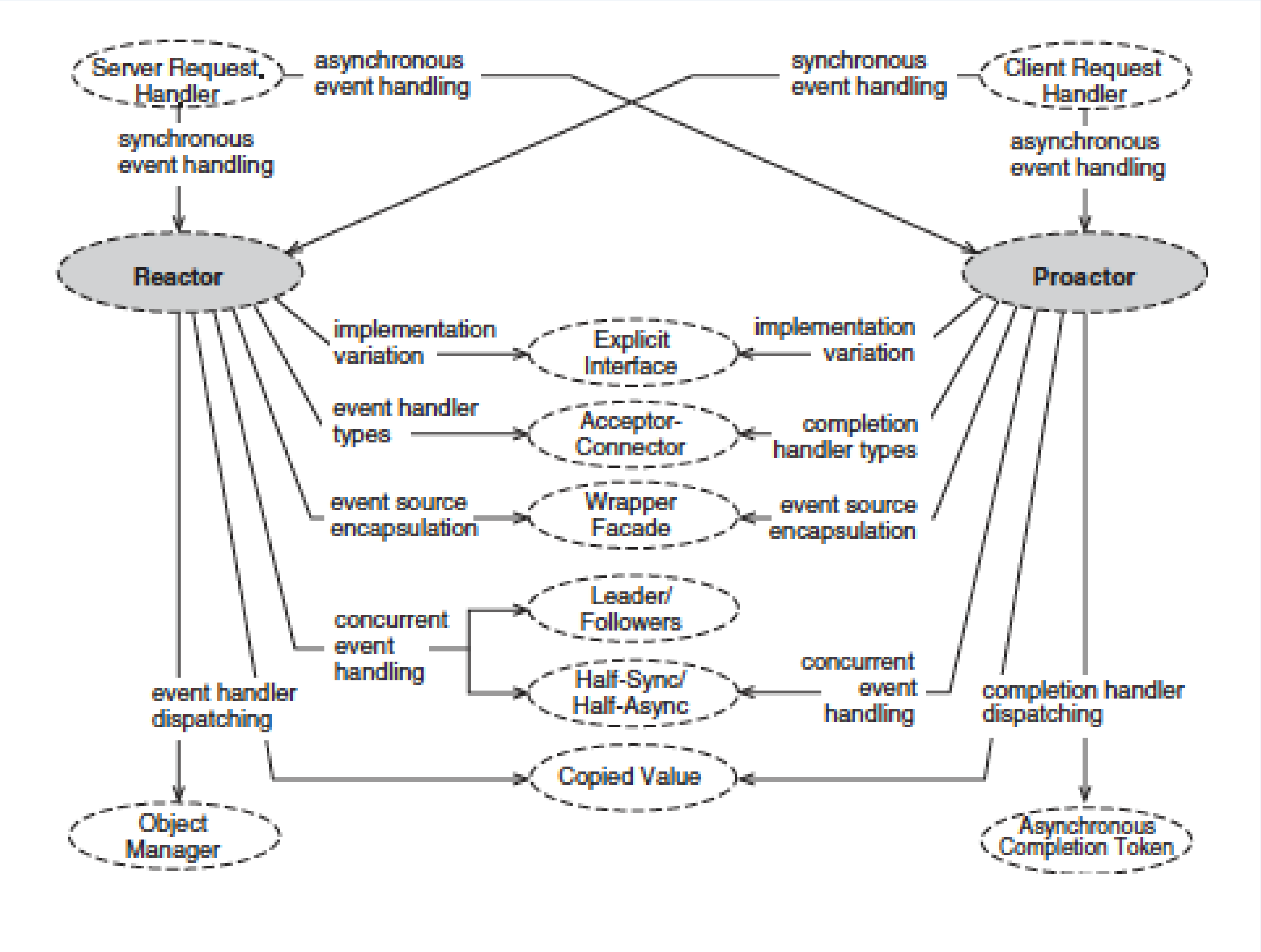
- Although both patterns resolve essentially the same problem in a similar context, and also use similar patterns to implement their solutions, the concrete event-handling infrastructures they suggest are distinct, due to the orthogonal forces to which each pattern is exposed.

- REACTOR focuses on simplifying the programming of event-driven software.
  - It implements a ***passive*** event demultiplexing and dispatching model in which services wait until request events arrive and then react by processing the events synchronously without interruption.
  - While this model scales well for services in which the duration of the response to a request is short, it can introduce performance penalties for long-duration services, since executing these services synchronously can unduly delay the servicing of other requests.

Reactor vs. Proactor

- PROACTOR is designed to maximize event-driven software performance.
  - It implements a more *active* event demultiplexing and dispatching model in which services divide their processing into multiple self-contained parts and
  - ***proactively initiate asynchronous execution*** of these parts.
  - This design allows multiple services to execute concurrently, which can increase quality of service and throughput.

- REACTOR and PROACTOR are not really equally weighted alternatives, but rather are complementary patterns that trade-off programming simplicity and performance.
  - Relatively simple event-driven software can benefit from a REACTOR-based design, whereas
  - PROACTOR offers a more efficient and scalable event demultiplexing and dispatching model.



Server Request Handler
asynchronous event handling
synchronous event handling
Client Request Handler
synchronous event handling
asynchronous event handling
Reactor
Proactor
implementation variation
Explicit Interface
implementation variation
event handler types
Acceptor-Connector
completion handler types
event source encapsulation
Wrapper Facade
event source encapsulation
concurrent event handling
Leader/ Followers
Half-Sync/ Half-Async
concurrent event handling
event handler dispatching
completion handler dispatching
Copied Value
Object Manager
Asynchronous Completion Token

Middleware

- In computer science, a middleware is a software layer that resides between the application layer and the operating system.

- Its primary role is to bridge the gap between application programs and the lower-level hardware and software infrastructure, to coordinate how parts of applications are connected and how they inter-operate.

- Middleware also enables and simplifies the integration of components developed by different technology suppliers.

Middleware

Examples of a middleware for distributed object-oriented enterprise systems: CORBA, SOAP.

- Despite their detailed differences, middleware technologies typically follow one or more of three different communication styles:
  - Messaging
  - Publish/Subscribe
  - Remote Method Invocation

Referinte

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