Distributed Systems

8. Mobile Agents

Motivation for mobile computation (1)

- *Pervasive* Networking and Computing
  - Connectivity and computing is cheap and available
- *Ubiquitous* Networking and Computing
  - Connectivity and computing power is available everywhere (independently from location)
- *Mobile* Computing
  - Network nodes can be placed everywhere
  - Wireless communication
- Easy-to-use Technologies for naive users
  - World Wide Web
    - Electronic commerce
    - Internet phone

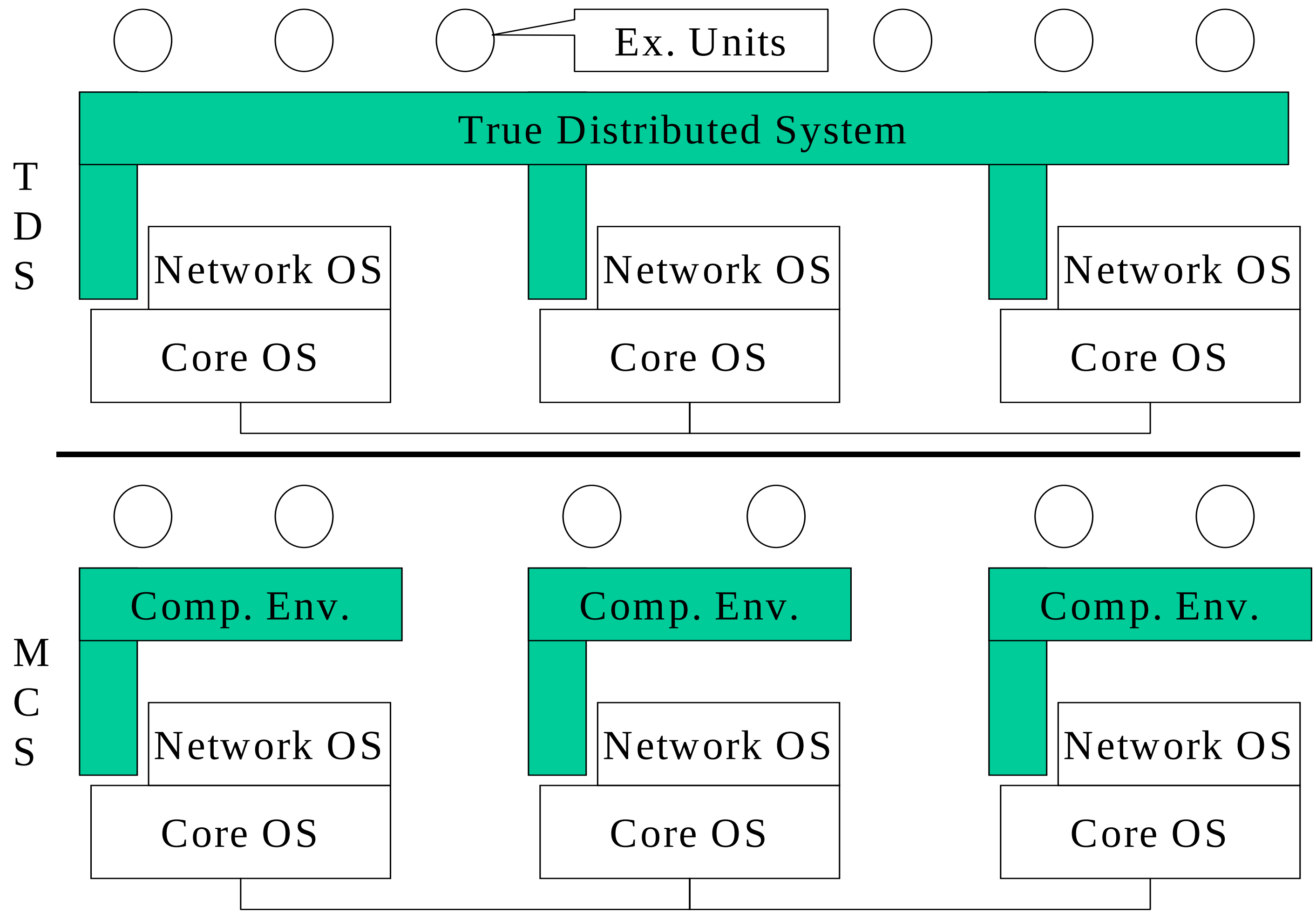
Motivation for mobile computation (2)

- Growing need for scalability
- Diffusion of network services and applications to large segments of the society
  - Customizability
  - Flexibility
  - Extensibility
- Well-established models and technologies
  - Essentially RPC-based
    - CORBA etc.
- Code mobility
  - The capability to dynamically change the bindings between code fragments and the location of execution

Code Mobility (1)

- A true distributed system is *location transparent*
- In a Mobile Computing System (MCS), applications are *location-aware*
  - Computational Environment (CE)
    - Location of the execution
  - Executions Units (EU)
    - Sequential flow of computation (e.g. a thread)
    - Code segment, data space, execution state
  - Resources
    - Sharable among EUs (e.g. files)

Code Mobility (2)



Strong mobility

- Code, data space *and* execution state of an EU migrate
- Migration
  - The EU is suspended, moved to the new CE and resumed
- Remote Cloning
  - Creates a copy of the running EU at the remote CE
  - The original EU is not detached
- Proactive migration or cloning
  - Time and destination are determined by the migrating EU
- Reactive migration or cloning
  - Time and destination are determined by another EU
- Strong mobility is entirely transparent to the user
- The transmitted code just resumes on the new CE
- Expensive

Weak mobility

- Code and data space can migrate, but *not* the execution state
- The migrated code will be restarted at a given procedure
  - It starts in a similar way as an interrupt-handler
- Fetch or ship
  - Either an EU fetches the code dynamically or ships code to execute to another CE
- Stand-alone code or code fragment
  - Stand-alone code instantiates a new EU
  - A code fragment is linked to an already running code
- Synchronous or asynchronous mobility
  - Synchronous: requesting EU suspends execution
  - Asynchronous: immediate or deferred

Data Space Management (1)

- Upon migration, bindings to resources must be rearranged
- Resource = (I, V, T)
  - I: unique identifier
  - V: value
  - T: type
  - Transferable vs. Not transferable
    - Principally not transferable is e.g. a printer
    - Transferable resources maybe
      - Free – can be freely migrate to another CE (e.g. a memory block)
      - Fixed –associated to a CE (e.g. a huge file)

Data Space Management (2)

- Resource binding to an EU may be
  - *By identifier*
    - The EU requires to be bound to a uniquely identified resource that cannot be substituted
    - E.g. a connection to a certain database
  - *By value*
    - The value (content) of the resource must not change due to the migration
    - The identity of the resource is not relevant
    - E.g. the value of a variable
  - *By type*
    - Bound resource must be compliant with a given type
    - Identity and value of the resource are not relevant
    - E.g. a system resource such as some network connection, or a block of memory

Data Space Management (3)

- Different bindings to the same resource is meaningful. E.g.
  - An EU makes a binding by identifier to its display
  - It makes a binding by type to the same resource
  - After roaming it has actually two displays:
    - The first one permanently associated to the original CE
    - The second one at the actual CE, wherever it is
- Two classes of problems in data space management
  - Resource relocation
  - Binding reconfiguration
- Let be *U* a migrating EU, with binding $B(\leftrightarrow)$ to resource *R*

Data Space Management (4)

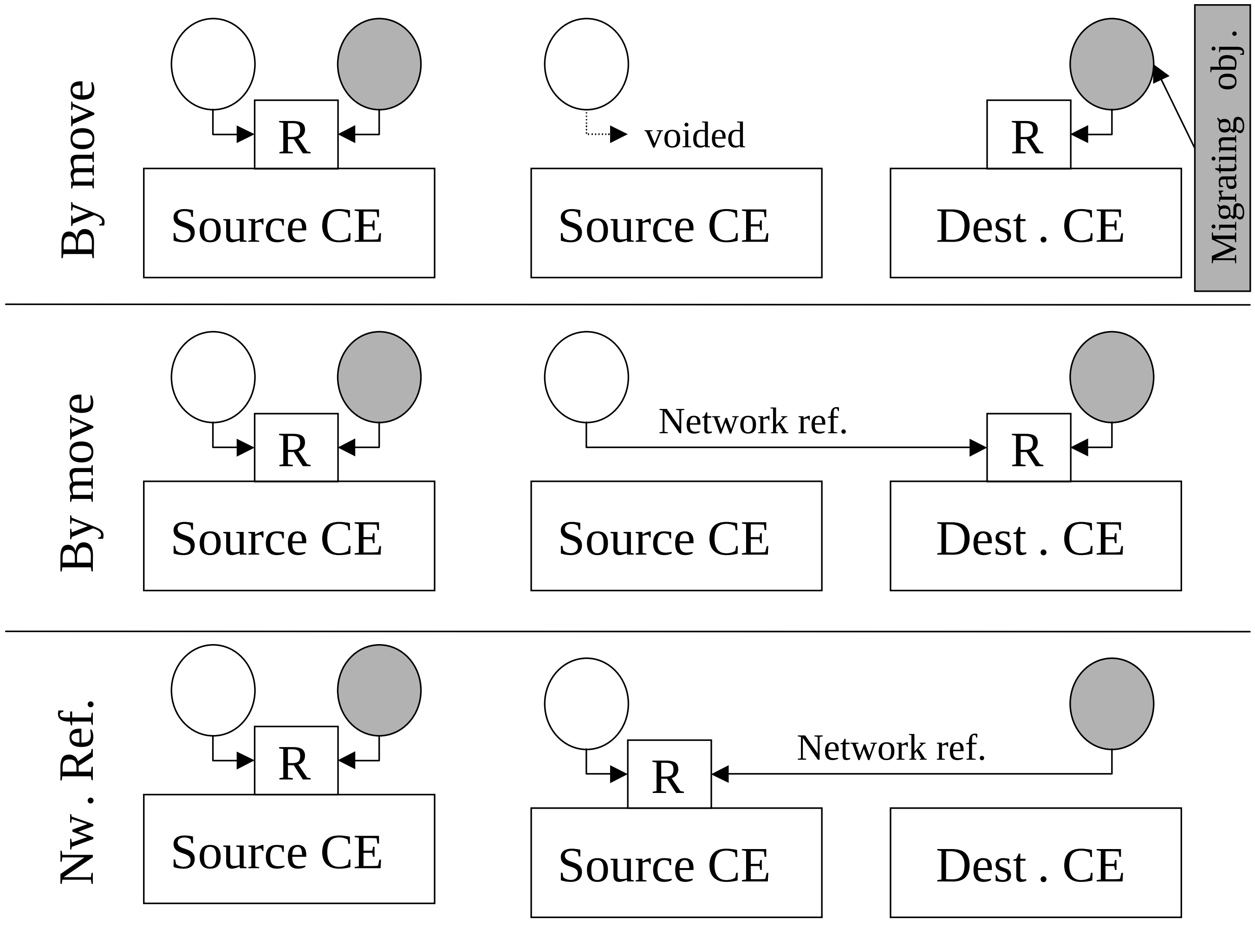
- *U* ↔ *R* by identifier
  - *Relocation by move*
    - Possible, if the resource is free transferable
    - May cause problems to other EUs with bindings to *R*
      - The other bindings might be removed
      - Or network references can be used to the new CE
  - *Network reference*
    - If the resource is fixed
    - May cause lot of network traffic
- *U* ↔ *R* by value, *R* is transferable
  - *Migration by copy*
  - A copy *R'* of *R* is created at the new CE
  - *B* is changed on the new CE to a *B': U* ↔ *R'*
  - *Migration by move*
    - Possible, but generally inefficient
  - If *R* is transferable but fixed
    - *Network reference* must be used

Data Space Management (5)

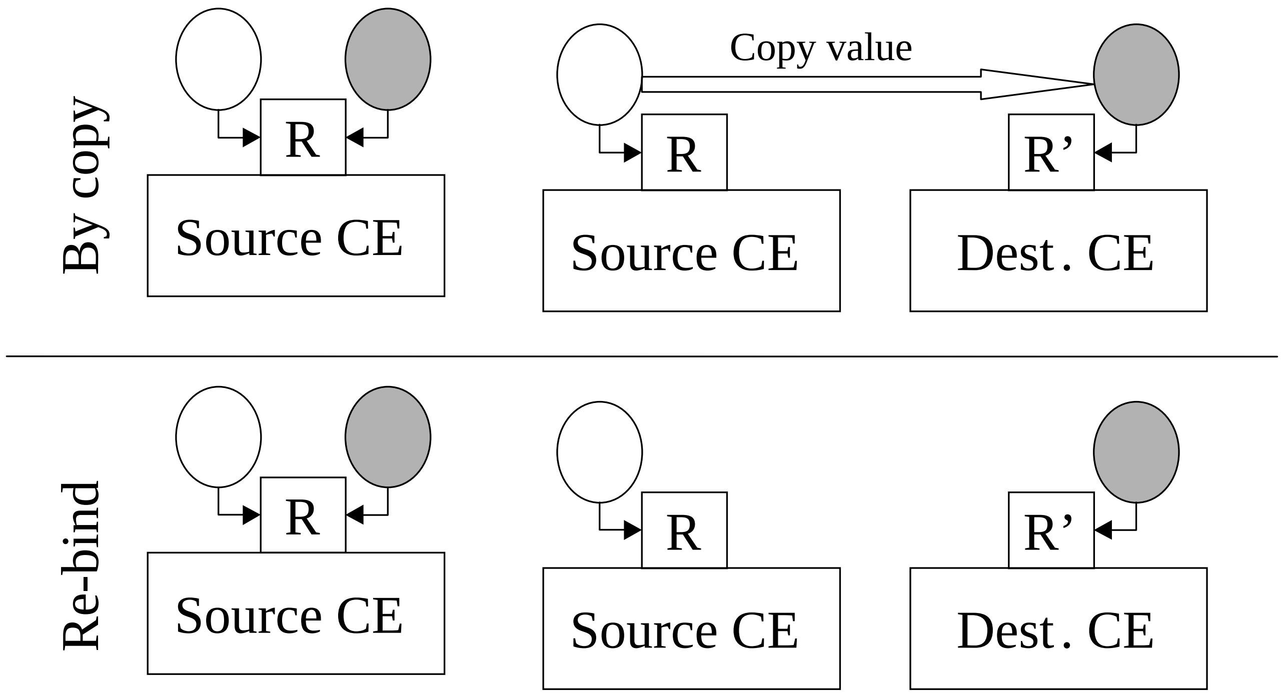
- *U* $\leftrightarrow$ *R* by type
  - *Re-binding*
    - B is voided at the old CE
    - B is re-established at the new CE to a new instance R'
    - No data transfer is necessary
    - A corresponding type and a free instance must exist!

Binding/ Res.	Free transf.	Fixed transf.	Not transf.
By identifier	move (nw. ref)	network ref.	network ref.
By value	copy (mo, nw. ref.)	copy (network ref.)	network ref.
By type	Re-binding (co, mo, n.r.)	Re-binding (co, n.r.)	Re-binding (network ref.)

Data Space Management (6)



Data Space Management (7)



Design Paradigms (1)

- Components
  - Code components – represents algorithms
  - Resource components – data or devices
  - Computational components – processors
- Interactions
  - Events involving two or more components
- Sites
  - Hosts computational components
  - They represent the locations
- Interactions among components on the same site are cheaper than those located on different sites
- We assume that a computation can be carried out, if the following are all on the same site
  - The know-how describing the computation
  - The resources used during the computation
  - The corresponding computational component

Design Paradigms (2)

- The computational component *A* at site S_a needs a service. There is a site S_b that is involved in the service
- Louise and Christine interact and cooperate to make a cake (result of the computation). They need
  - A recipe (the know-how about the service)
  - The ingredients (movable resources)
  - An oven (a not moveable resource)
  - A person making the cake (computational component)
- The main design paradigms are
  - Client/Server
  - Remote Evaluation
  - Code on Demand
  - Mobile Agents

Client-Server

- Louise would like to have a cake
- She does not know the recipe and she has neither ingredients nor an oven
- She calls Christine and asks her to make a cake for her
- Christine makes the cake and delivers it to Louise
- The client component *A* at site S_a sends a request to site S_b
- The server component *B* at site S_b performs the service using its own resources and returns the result to *A*

Remote Evaluation (REV)

- Louise wants to prepare the cake
- She knows the recipe but she has neither ingredients nor an oven
- She calls Christine, tells her the recipe and asks her to make such a cake for her
- Christine makes the cake and delivers it to Louise
- The client component *A* at site S_a sends the know-how (a procedure) to site S_b
- The server component *B* at site S_b performs this procedure using its own resources and returns the result to *A*.

Code on Demand (CoD)

- Louise wants to prepare the cake
- She has both ingredients and oven, but she lacks the recipe
- She calls Christine, and asks her to tell the recipe
- Louise makes the cake
- The client comp. *A* at site S_a has the necessary resources but no procedure to process them
- It asks for the know-how at site S_b
- The server component *B* at site S_b delivers the know-how
- The client component *A* at site S_a executes this procedure

Mobile Agent (MA)

- Louise wants to prepare the cake
- She has both ingredients and the recipe, but no oven
- She prepares the cake
- She goes to Christine and completes the cake in her oven
- She eats it there or comes back with the cake
- The client component *A* at site S_a has the know-how
- Some of the required resources are at site S_b
- *A* migrates to site S_b, carrying the know-how and maybe some intermediate results (some data) with
- *A* completes the computation at site S_b, using its resources
- As opposed to REV and CoD, a whole computational component (incl. state and some resources) is moved

Selection of the paradigm

- There is no best paradigm nor a best technology
- Paradigm and technology are principally orthogonal
- In practice, they must conform to each other and application
- So, we have to clearly distinguish
  - The application or application domain (e.g. a system to control a remote telescope)
  - The design paradigm (e.g. Remote Evaluation)
  - The technology used (e.g. Java Aglets)
- Mobile code applications are still rare
- Performance
  - Mobile code is usually executed by an interpreter

Security issues

- If code can move easily, malicious code can this as well
- Authentication of the sender of mobile code
  - A server may want to authenticate the client
  - The client may also want to authenticate the server
- Which rights has the migrated code at the destination
- Sandbox
  - Dangerous calls are restricted by security control components
- Organizational approach
  - Allow mobile agents only to trustworthy institutions
  - Maybe to institutions with “good reputation”
- Manipulation detection
  - Does not protect again read attacks
- Blackbox
  - Obfuscate and invalid code before the attacker has time to crack it

Key benefits of mobile code (1)

- Service customization
  - Traditional Client/Server systems provide a fixed set of services – that is regularly upgraded by new versions
  - An alternative way is a simple server with dynamically extensible functionality provided by the client
- Deployment and maintenance
  - The new version of the software is installed on a server
  - Clients may load and dynamically link code fragments on demand – lazy propagation
- Autonomous Components
  - Communication channels have often low-bandwidth and low-reliability (e.g. wireless)
  - Constant connection is therefore not available (no C/S)
  - The user sends a single request to a stationary agent
  - The stationary agent makes the job, while e.g. the mobile equipment might be switched off

Key benefits of mobile code (2)

- Fault tolerance
  - In the client/server model the global state is distributed
  - Mobile agents just take their local state with themselves
- Protocol Encapsulation
  - Traditionally communication protocols must be installed at both peer entities
  - With mobile code one basic protocol suffices
  - Additionally, more sophisticated protocols can be downloaded with the help of the basic protocol
- Software Engineering
  - Mobile agents are well-suited to make rapid prototypes of a distributed system
  - Instead of a full installation, only a basic environment is installed
  - Prototyping code is distributed as mobile agents

Application Domains (1)

- Distributed Information Retrieval
  - Classical example for the MA paradigm
    - A mobile agent visits different hosts
    - It applies dynamic routing based on actual information
    - It performs search and filtering at the source of information, such decreasing network traffic
- Active Documents
  - Traditionally passive documents (as e-mail or Web pages) may be turned to be active by taking some code with
  - E.g. an e-mail takes the presentation software with it, thus allowing a presentation close to the original
  - E.g. an application that uses graphic forms to express queries to a remote database
    - The user requests the active document (CoD) and uses it as an interface (e.g with WWW+Java applets)

Application Domains (2)

- Advanced Telecommunication Services
  - Videoconference, video on demand, telemeeting etc.
  - They need dynamic reconfiguration and customization
  - E.g. the setup, signaling and presentation services could be dispatched to the users by a broker (REV)
- Remote Device Control and Configuration
  - E.g. network management
  - Configuration and monitoring code can be shipped (REV)
- Workflow Management
  - A mobile agent leads the workflow document through all stages of its processing in a distributed environment
- Active Networks (CoD)
  - E.g. routers can be dynamically "reprogrammed"
- Electronic Commerce
  - User transactions are carried out by a mobile agent

Mobile Agents

- Autonomous objects with behavior, state and location
  - Can but need not to be “intelligent“ (in the sense of AI)
- Mobile Agent ↔ Service Agent Interaction
  - Client/server like
  - Ideally an RPC-like mechanism is provided
- Mobile Agent ↔ Mobile Agent Interaction
  - Peer-to-peer, rather than client/server like
  - Often not just request/response, general message passing
- Anonymous Agent Group Interaction
  - The sender often does not know the receiver
    - E.g. a group of agents is working on a problem
    - The sender knows the group but not the individual agent
    - Group communication can be used to this purpose
    - Event channels can be used as well – additional level of indirection

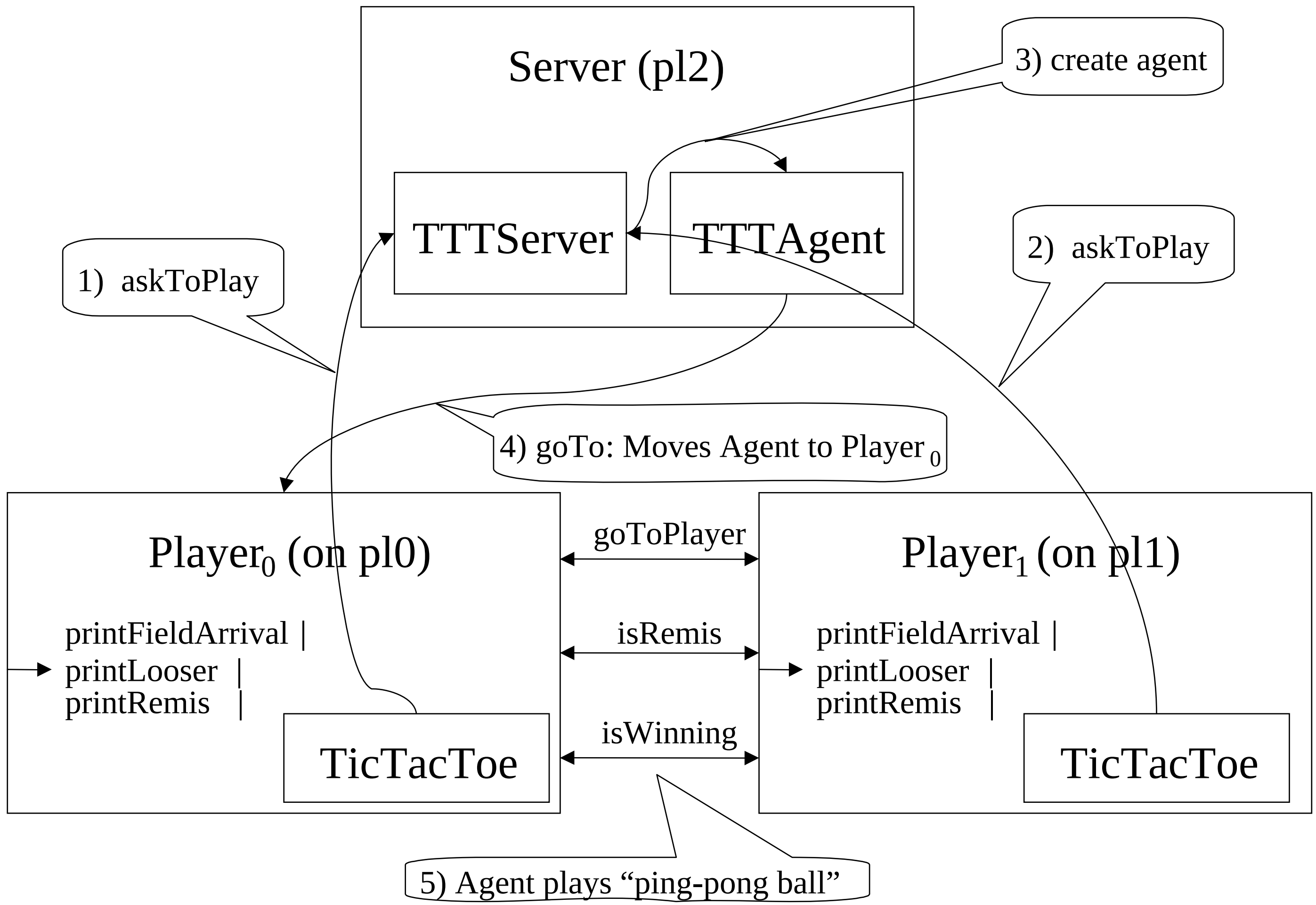
Some available mobile agent systems

	Languages	Mobility	Source	Avail.
Tacoma	Tcl, C, ...	REV	Uni Cornell	free
J. Servlets	Java	REV(push) COD (pull)	Sun	binary
J. Applets	Java	COD	Sun	binary
Active X	C, C++, ...?	COD	Microsoft	binary
Aglets	Java	Weak migr	IBM	binary
Mole	Java	Weak migr	Uni Stuttgart	free
Odyssey	Java	Weak migr	General Magic	binary
Voyager	Java	Weak migr	ObjectSpac	binary
AgentTcl	Tcl	Strong migr	Dartmouth	free
Ara	Tcl, C, Java	Strong migr	Uni Kaiserslaut	free
Jade	Java	Weak migr	TLAB, Torino	free
Emerald	Emerald	Strong migr	Uni Washington	free

Example MA, TicTacToe (1)

- The *TicTacToe* class is located statically at the client sites
  - It may emit *askToplay* calls, on user demand
- The sever site accepts and answers these calls
  - The 1. player must wait until a second is coming
  - If the 2. request arrives, the sever creates an agent and passes it to the 1. player (Player0), via the *goTo* method
- The players send the agent back and forth with the actual state of the game, via the *goToPlayer* method
- The agent starts running at the destination site at a method specified by the source site
- The selection of the method depends on state of the game (e.g. *printRemis* for undecided)
- If the game is over (one player *wins* resp. remis) they shut down the voyager daemon

Example MA, TicTacToe (2)



Example MA, TicTacToe (3)

```
public class TTTAgent implements ITTTAgent, Serializable  {

    public void goTo()  {
    //Called by the server. It sends the agent to player0
        try  {  // Agent's execution there starts at printFieldArrival
            Agent.of(this).moveTo(players[0], "printFieldArrival");
        . . . }  }

    public void printFieldArrival()   { . . . make own move …  playTurn();   }

    public void playTurn()      // Checks input and the effect of it
    { . . .
        if (game not ended yet) {
            goToPlayer("printFieldArrival");
            else if (remis) { isRemis() }
            else if (winner) { isWinning() }
    }  }
```

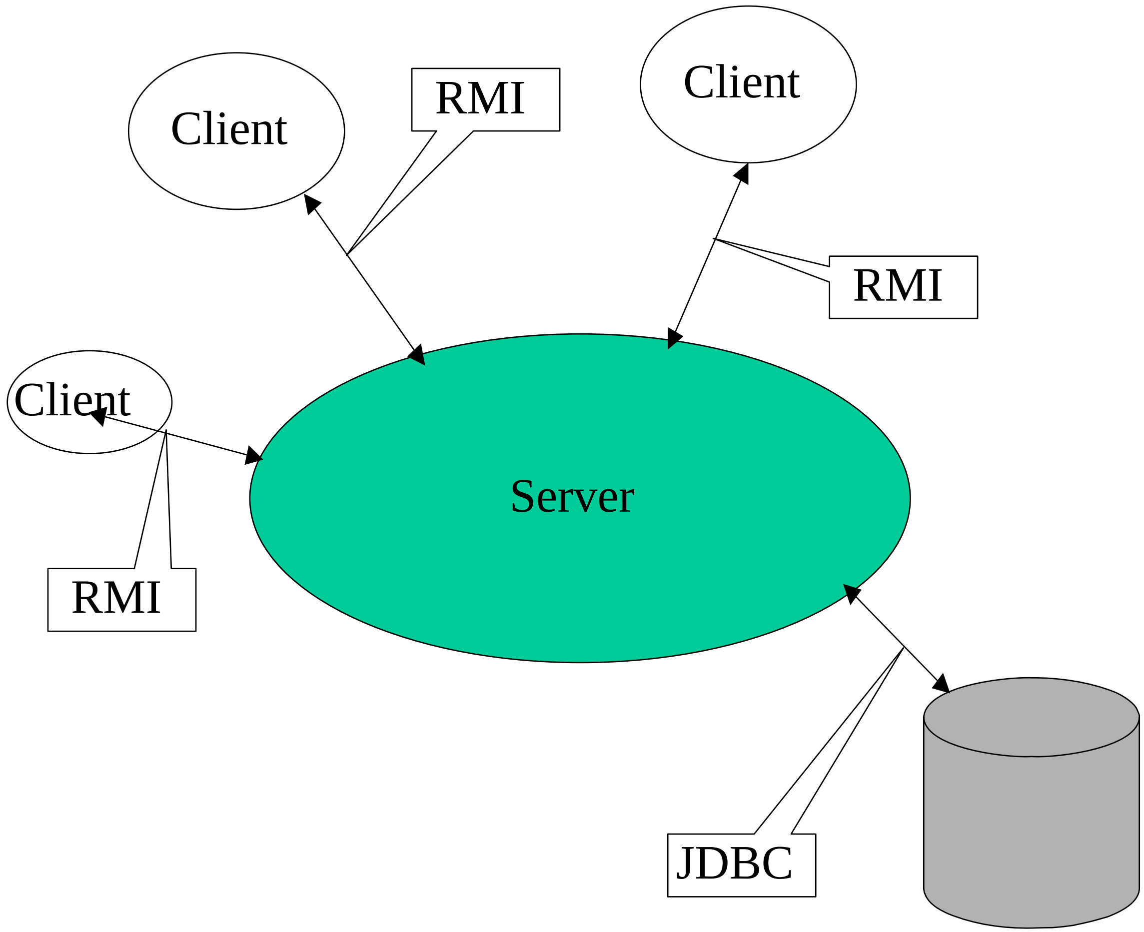
Example MA, TicTacToe (4)

```
public void isWinning()          //Print winning message
    { goToPlayer("printLooser");
     Voyager.shutdown();   }

public void printLooser()   //Print losing message
    { Agent.of(this).setAutonomous(false);
     Voyager.shutdown();   }

public void goToPlayer(String callback)   {
// Agent is moved – incl. instance variables (state of the game)!
// The actual value of callback depends on the state of the game.
// For normal case, printFieldArrival, for remis printRemis ...
try {
    Agent.of(this).moveTo(players[actual++ % 2], callback);
. . .   } }
```

Example CoD, Server-Defined Policy (1)

- Server communicates with the clients via RMI and with a relational database via JDBC.
- Clients
  - Create expense records
  - Check the validity of the expense records
  - Send the proper reports to the server
- Server
  - Stores them in the database
  - The validation policy may change
  - The computation for validation the expense record can be offloaded from the server to the client
  - The policy for this check can be changed without any change in the client code

Example CoD, Server-Defined Policy (2)



Example CoD, Server-Defined Policy (3)

- The client may use the following interface remotely:

```
public interface ExpenseServer extends Remote {
    Policy getPolicy() throws RemoteException;
    void submitReport(ExpenseReport report)
            throws RemoteException, InvalidReportException;
} // ExpenseServer
```

- The policy interface itself is non-remote, a policy object will be copied to the client, who may use the *checkValid* method locally

```
public interface Policy {
    void checkValid(ExpenseEntry entry)
            throws PolicyViolationException;
} // Policy
```

Example CoD, Server-Defined Policy (4)

- A typical client looks like

```
Policy curPolicy = server.getPolicy();
// start a new expense report
// show the GUI to the user
 while (user keeps adding entries) {
     try {
             curPolicy.checkValid(entry);
             // add the entry to the expense report
     } catch (PolicyViolationException e) {
             // show the error to the user
     } // try
} // while
server.submitReport(report);
```

Example CoD, Server-Defined Policy (5)

- Implementation of the server:

```
class ExpenseServerImpl
    extends UnicastRemoteObject,
                implements ExpenseServer  {
    ExpenseServerImpl() throws RemoteException { … }

    public Policy getPolicy() {
        return new TodaysPolicy();
    }

    public void submitReport(ExpenseReport report) {… }
} // ExpenseServerImpl
```

Example CoD, Server-Defined Policy (6)

- The actual policy is defined by the following class

```
public class TodaysPolicy implements Policy {
    public void checkValid(ExpenseEntry entry)
            throws PolicyViolationException
    {
            if (entry.dollars() < 20) {
                    return;         // no receipt required
            } else if (entry.haveReceipt() == false) {
                    throw new PolicyViolationException;
            } // if
    } // checkValid
} // TodaysPolicy
```

Example CoD, Server-Defined Policy (7)

- To change the policy
  - Provide a new implementation of the interface *Policy*
  - Server returns *TomorrowsPolicy* instead of *TodaysPolicy* objects

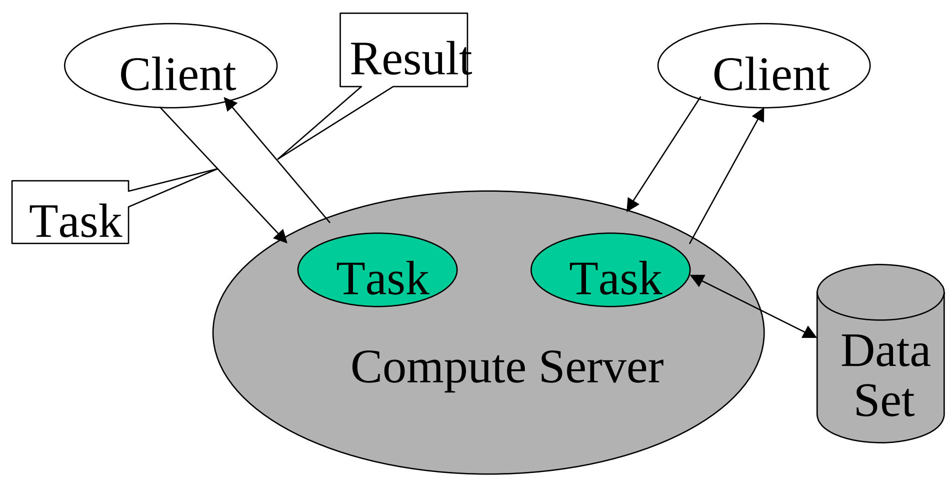
```
public class TomorrowsPolicy implements Policy {
    public void checkValid(ExpenseEntry entry)
            throws PolicyViolationException  {
            if (entry.isMeal() && entry.dollars() < 20) {
                    return;   // no receipt required
            } else if (entry.haveReceipt() == false) {
                    throw new PolicyViolationException;
            } // if
    } // checkValid
} // TomorrowsPolicy
```

Example REV, Compute Server (1)

- We want to delegate some computations to a special compute (e.g. very fast) server
- *Task* is a non-remote interface, with a *run* method that can be overridden by any computation. The signature of *run* is as "generic" as possible

```
public interface Task { Object run(); }
```

- The remote server takes a task from a client, executes it and returns the result.



Example REV, Compute Server (2)

```
public interface ComputeServer extends Remote {
    Object compute(Task task) throws RemoteException;
} // ComputeServer
public class ComputeServerImpl
    extends UnicastRemoteObject, implements ComputeServer {
    public ComputeServerImpl()  throws RemoteException { . . . }

    public Object compute(Task task) { return task.run(); }  // comp.+result

    public static void main(String[] args) throws Exception {
        System.setSecurityManager(new RMISecurityManager());
        ComputeServerImpl server = new ComputeServerImpl();
        Naming.rebind("ComputeServer", server);
        System.out.println("Ready to receive tasks");
        return;
    } // main
} // ComputeServerImp
```