Code Migration in Distributed Systems

Distributed Software Systems

Motivation for Code Migration

- Load Sharing in Distributed Systems
  - Long-running processes can be migrated to idle processors
- Client-server systems
  - Code for data entry shipped to client system
  - If large quantities of data need to be processed, it is better to ship the data processing component to the client
  - Dynamically configurable client software
    - More flexibility, Easier maintenance and upgrades of client software
- Enterprise and "Desktop Grids", e.g. SETI@home
  - Computationally-intensive tasks shipped to idle PCs around the network

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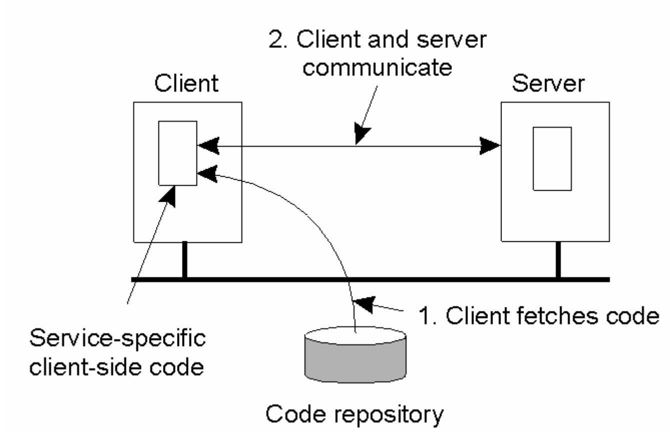
Dynamically Configurable Client Software

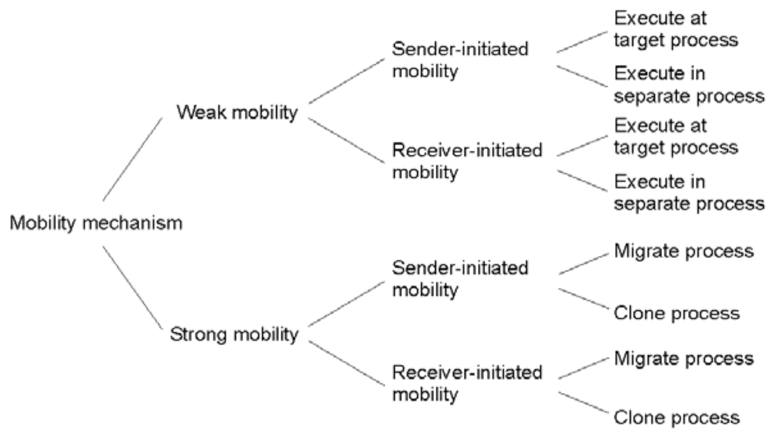


The principle of dynamically configuring a client to communicate to a server. The client first fetches the necessary software, and then invokes the server.

Models for Code Migration

- A process has three segments
  - Code segment
  - Execution segment – private data, stack, PC, registers
  - Resource segment – references to external resources such as files, printers, devices, etc
- Weak vs strong mobility
  - weak mobility: only code segment + initialization data migrated, e.g. Java applets
  - strong mobility: code segment + execution segment
- Sender-initiated vs receiver-initiated migration

Models for Code Migration



Alternatives for code migration.

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Migration and Local Resources

- Process-to-resource bindings make code migration difficult
- Three types of process to resource bindings
  - Binding by identifier – when a process refers to a resource by its identifier, e.g. URL, IP address, local communication endpoint (socket)
  - Binding by value – weaker form of binding when only the value of a resource is needed, e.g. when a program relies on standard language libraries
  - Binding by type – weakest form of binding when a process indicates the type of a resource, e.g., a printer

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Migration and Local Resources (cont'd

- When migrating code, we may need to change the references to resources but cannot change the kind of process-to-resource binding.
- How a resource reference is changed depends on the resource-to-machine bindings
  - Unattached resources can be easily moved, e.g. data files associated only with the program being moved
  - Fastened resources can be moved at a high cost, e.g. a database
  - Fixed resources cannot be moved, e.g., local devices, local communication endpoint

Migration and Local Resources cont'd

Resource-to machine binding

		Unattached	Fastened	Fixed
Process-to-resource binding	By identifier	MV (or GR)	GR (or MV)	GR
	By value	CP (or MV, GR)	GR (or CP)	GR
	By type	RB (or GR, CP)	RB (or GR, CP)	RB (or GR)

GR: Establish a global system-wide reference
MV: move the resource
CP: copy the value of the resource
RB: Rebind process to locally available resource

Actions to be taken with respect to the references to local resources when migrating code to another machine.

Migration in heterogeneous systems

- Weak mobility: no runtime information needs to be transferred, so it suffices to generate separate code segments for different target platforms
- Strong mobility: how to transfer the execution segment
  - One approach: runtime systems maintains a language-independent copy of the program stack
  - More common approach: Use a virtual machine

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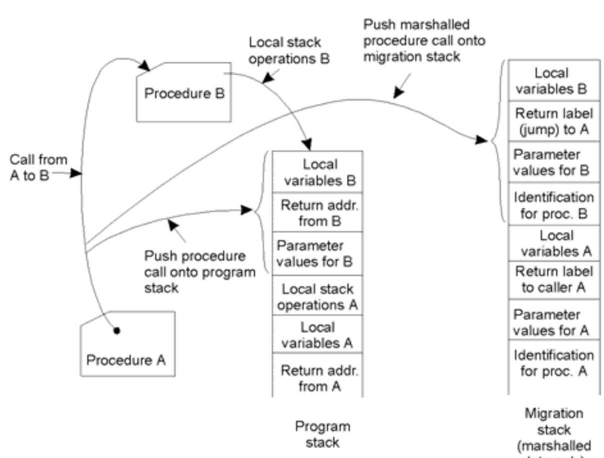
Migration in Heterogeneous Systems

The principle of maintaining a migration stack to support migration of an execution segment in a heterogeneous environment



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Overview of Code Migration in D'Agents (1)

```
proc factorial n {
   if ($n ≤ 1) { return 1; }                # fac(1) = 1
  expr $n * [ factorial [expr $n – 1] ]     # fac(n) = n * fac(n – 1)
}
set number …         # tells which factorial to compute
set machine …        # identify the target machine

agent_submit $machine –procs factorial –vars number –script {factorial $number }

agent_receive …      # receive the results (left unspecified for simplicity)
```

A simple example of a Tel agent in D'Agents submitting a script to a remote machine

Example: D'Agents

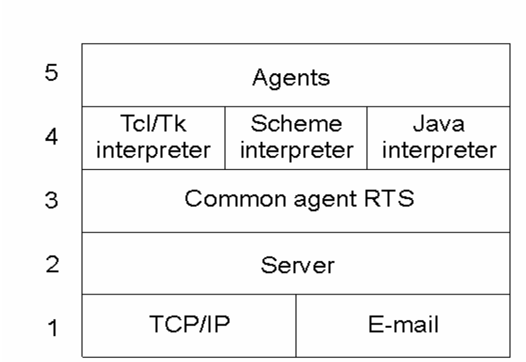
- D'Agents: research middleware platform that supports various forms of code migration
- Agent is a program that can migrate between heterogeneous platforms
  - written in Tcl, Scheme, or Java
- Agent mobility
  - Sender-initiated weak mobility: agent_submit command
  - Strong mobility by process migration: agent_jump command
  - Strong mobility by process cloning: agent_clone
    - agent_clone similar to agent_jump except that invoking process continues execution at the source machine

Overview of Code Migration in D'Agents (2)

```
all_users $machines

proc all_users machines {
    set list ""                    # Create an initially empty list
    foreach m $machines {          # Consider all hosts in the set of given machines
        agent_jump $m              # Jump to each host
        set users [exec who]       # Execute the who command
        append list $users         # Append the results to the list
    }
    return $list                   # Return the complete list when done
}

set machines …                     # Initialize the set of machines to jump to
set this_machine                   # Set to the host that starts the agent

# Create a migrating agent by submitting the script to this machine, from where
# it will jump to all the others in  $machines.

agent_submit $this_machine –procs all_users
                           -vars  machines
                           -script { all_users $machines }

agent_receive …                    #receive the results  (left unspecified for simplicity)
```

An example of a Tel agent in D'Agents migrating to different machines where it executes the UNIX *who* command

Implementation Issues (1)



The architecture of the D'Agents system.

- The Server is responsible for agent management, authentication, and management of communication between agents
- The RTS layer supports the core functionality of the system, i.e., creation of agent, migration, interagent communication, etc.

Implementation Issues (2)

Status	Description
Global interpreter variables	Variables needed by the interpreter of an agent
Global system variables	Return codes, error codes, error strings, etc.
Global program variables	User-defined global variables in a program
Procedure definitions	Definitions of scripts to be executed by an agent
Stack of commands	Stack of commands currently being executed
Stack of call frames	Stack of activation records, one for each running command

The parts comprising the state of an agent in D'Agents.

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Software Agents

- A software agent is an autonomous process capable of reacting to, and initiating changes in its environment, possibly in collaboration with users and other agents
  - Collaborative agents
    - part of a multi-agent system in which agents try to achieve some common goal through collaboration
  - Mobile agents
    - capable of moving between systems
  - Interface agents
    - agents that assist an end user in the use of one or more applications
    - have learning capabilities
  - Information agents
    - manage information from many different sources

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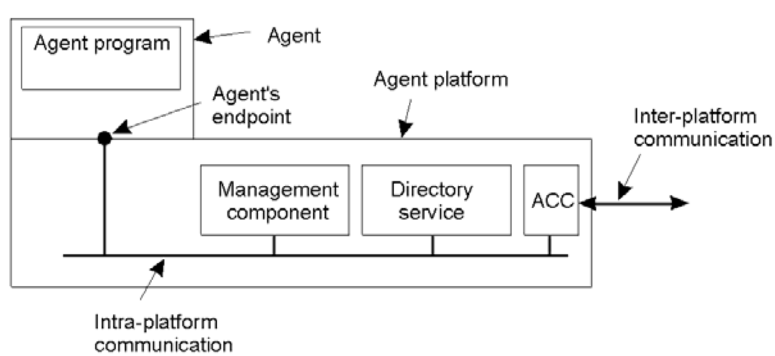
Software Agents in Distributed Systems

Property	Common to all agents?	Description
Autonomous	Yes	Can act on its own
Reactive	Yes	Responds timely to changes in its environment
Proactive	Yes	Initiates actions that affects its environment
Communicative	Yes	Can exchange information with users and other agents
Continuous	No	Has a relatively long lifespan
Mobile	No	Can migrate from one site to another
Adaptive	No	Capable of learning

Some important properties by which different types of agents can be distinguished.

Agent Technology



The general model of an agent platform

Agent Communication Languages (1)

Message purpose	Description	Message Content
INFORM	Inform that a given proposition is true	Proposition
QUERY-IF	Query whether a given proposition is true	Proposition
QUERY-REF	Query for a give object	Expression
CFP	Ask for a proposal	Proposal specifics
PROPOSE	Provide a proposal	Proposal
ACCEPT-PROPOSAL	Tell that a given proposal is accepted	Proposal ID
REJECT-PROPOSAL	Tell that a given proposal is rejected	Proposal ID
REQUEST	Request that an action be performed	Action specification
SUBSCRIBE	Subscribe to an information source	Reference to source

Examples of different message types in the FIPA ACL giving the purpose of a message, along with the description of the actual message content.

Agent Communication Languages (2)

Field	Value
Purpose	INFORM
Sender	max@http://fanclub-beatrix.royalty-spotters.nl:7239
Receiver	elke@iiop://royalty-watcher.uk:5623
Language	Prolog
Ontology	genealogy
Content	female(beatrix),parent(beatrix,juliana,bernhard)

A simple example of a FIPA ACL message sent between two agents using Prolog to express genealogy information.

Secure Mobile Code

- Mobile code introduces security threats
- Mobile agents need to be protected from malicious hosts
  - hosts may try to steal or modify information carried by the agent
- Hosts need to be protected against malicious agents
  - Viruses and worms are instances of (stealthy) malicious agents!!

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Protecting an agent

- Malicious hosts may
  - steal information carried by an agent
  - modify an agent to change its behavior
  - destroy an agent
- Fully protecting an agent against all kinds of attacks is impossible
- Alternative: organize agents in such a way that modifications can be detected
  - Example: Ajanta system

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Ajanta

- Three mechanisms that allow an agent's owner to detect that the agent has been tampered with
- Read-only state
  - Collection of data items signed by owner
    - message digest encrypted with private key
    - host can verify the received read-only state using the public key of owner
- Append-only logs
  - data collected by an agent can only be appended to the log
  - Initially checksum associated with empty log, $C_{init} = K^{+}(N)$, where N is a nonce and K^{+} is public key of owner

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Ajanta cont'd

- Append-only logs (cont'd)
  - When a server S appends X to the log, it calculates a new checksum $C_{new} = K^{+}(C_{old}, sig(S,X), S)$, where C_{old} is the previously used checksum
  - When the agent comes back to the owner, the owner can start reading the log at the end successively decrypting the checksum, until the initial checksum is reached
- Selective revealing of state
  - an array of data items, each intended for a designated server
  - each entry is encrypted with the designated server's public key
  - the entire array is signed by the agent's owner

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Protecting the target

- More critical problem than protecting an agent
- Approaches
  - create a **sandbox**, e.g. Java
    - a technique by which a downloaded program is executed in such a way that each of its instructions can be fully controlled
  - create a **playground**
    - a separate designated machine exclusively reserved for downloaded code
    - resources local to other machines are physically disconnected from the playground
    - users on other machines can access the playground using traditional means, e.g. RPC

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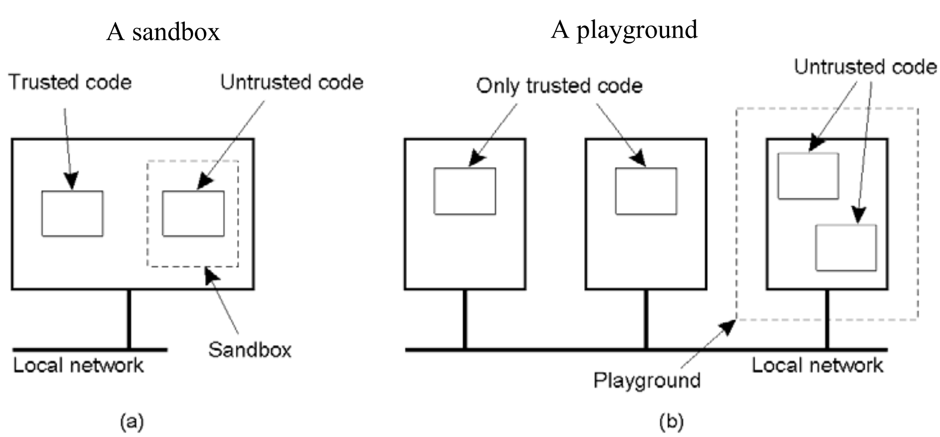
Sandbox vs Playground



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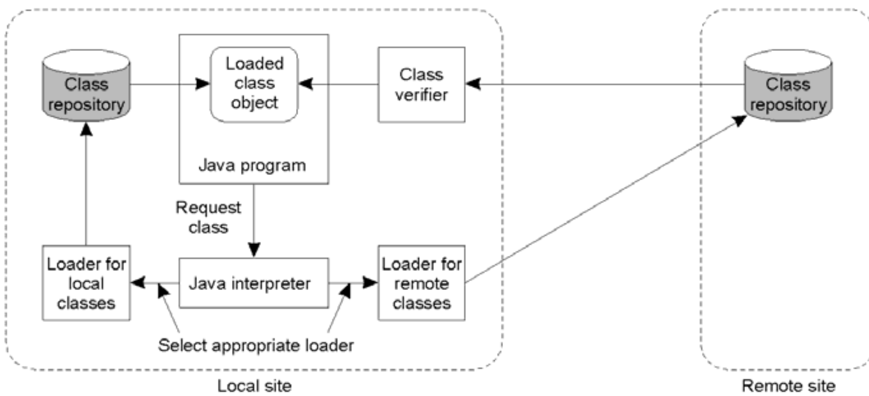
Java sandbox organization



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Java sandbox implementation

- Java sandbox components
  - Only trusted **class loaders** are used
  - **Byte code verifier** checks whether downloaded class contains illegal instructions or instructions that could corrupt the stack or memory
  - A **security manager** performs various checks at run-time to ensure that the downloaded object does not make any unauthorized access to client resources
    - e.g. checks I/O operations for validity, disallows access to local files, etc.

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Adding flexibility

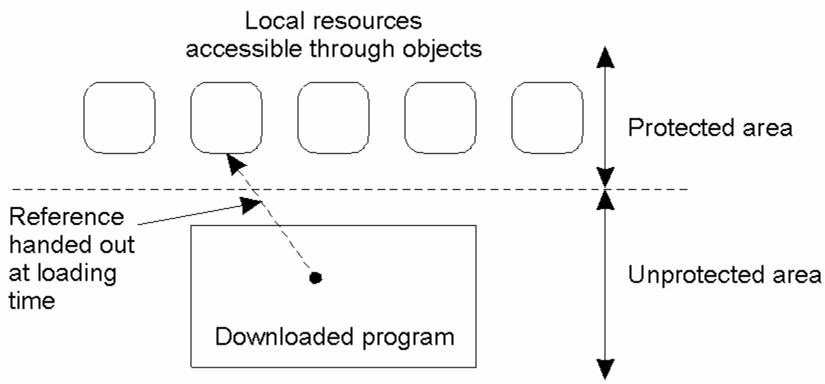
- Playgrounds are more flexible than sandboxes
- Next step: downloaded programs are authenticated, and subsequently a specific security policy is enforced based on the where the program came from
  - authentication achieved through digital signatures
  - enforcing a security policy more challenging

Enforcing security policies

- Wallach et al proposed three mechanisms for enforcing a security policy for Java programs
  - Use object references as capabilities
  - Stack introspection
  - Name space management
    - to access local resources, programs need to include the appropriate files that contain the classes implementing those resources
    - Interpreter enforces different policies for different downloaded programs by resolving the same name to different classes
- Language-independent solutions are more difficult to implement and require support from the OS

Enforcing security policies

The principle of using Java object references as capabilities.



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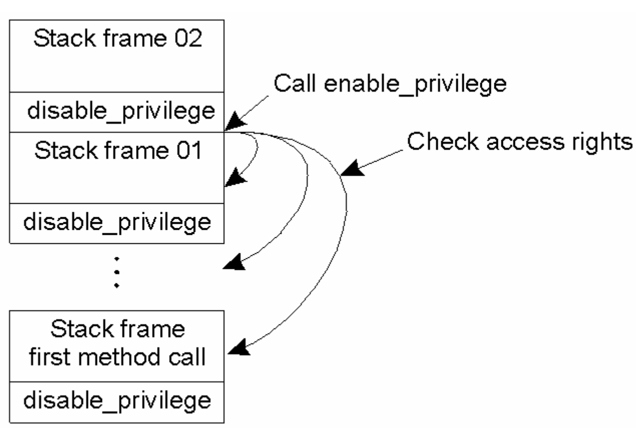
Enforcing security policies

The principle of stack introspection.



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