Process

Distributed Systems

Introduction to threads

Basic idea

We build virtual processors in software, on top of physical processors:

Processor: Provides a set of instructions along with the capability of automatically executing a series of those instructions.

Thread: A minimal software processor in whose context a series of instructions can be executed. Saving a thread context implies stopping the current execution and saving all the data needed to continue the execution at a later stage.

Process: A software processor in whose context one or more threads may be executed. Executing a thread, means executing a series of instructions in the context of that thread.

Context switching

Contexts

- Processor context: The minimal collection of values stored in the registers of a processor used for the execution of a series of instructions (e.g., stack pointer, addressing registers, program counter).
- Thread context: The minimal collection of values stored in registers and memory, used for the execution of a series of instructions (i.e., processor context, state).
- Process context: The minimal collection of values stored in registers and memory, used for the execution of a thread (i.e., thread context, but now also at least MMU register values).

Context switching

Observations

1. Threads share the same address space. Thread context switching can be done entirely independent of the operating system.
2. Process switching is generally (somewhat) more expensive as it involves getting the OS in the loop, i.e., trapping to the kernel.
3. Creating and destroying threads is much cheaper than doing so for processes.

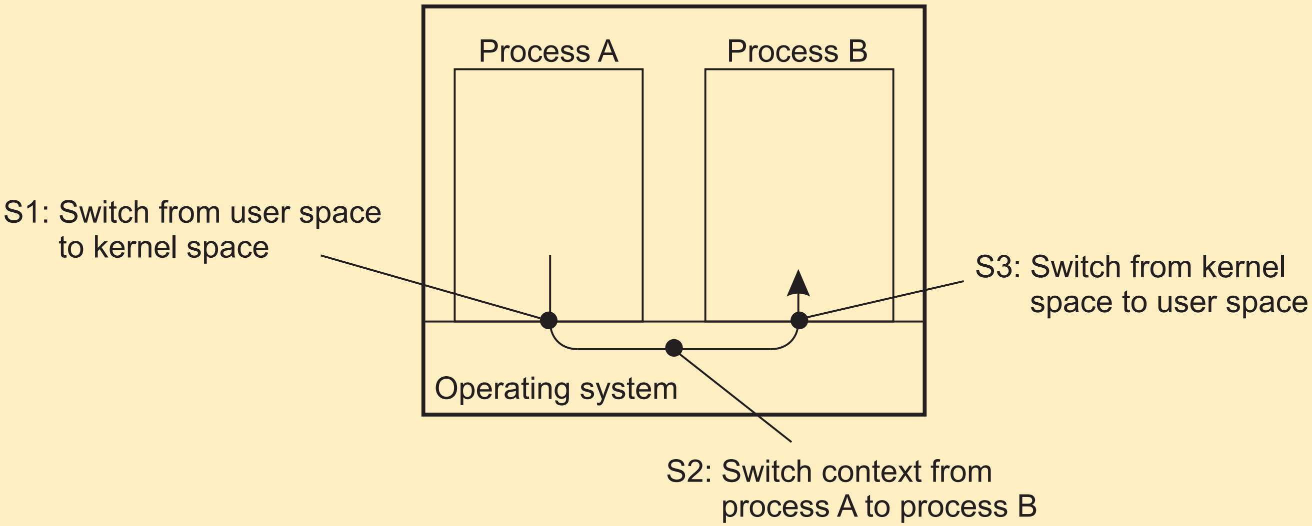
Why use threads

Some simple reasons

- Avoid needless blocking: a single-threaded process will block when doing I/O; in a multi-threaded process, the operating system can switch the CPU to another thread in that process.
- Exploit parallelism: the threads in a multi-threaded process can be scheduled to run in parallel on a multiprocessor or multicore processor.
- Avoid process switching: structure large applications not as a collection of processes, but through multiple threads.

Avoid process switching

Avoid expensive context switching



Trade-offs

- Threads use the same address space: more prone to errors
- No support from OS/HW to protect threads using each other's memory
- Thread context switching may be faster than process context switching

Using threads at the client side

Multithreaded web client

Hiding network latencies:

- Web browser scans an incoming HTML page, and finds that more files need to be fetched.
- Each file is fetched by a separate thread, each doing a (blocking) HTTP request.
- As files come in, the browser displays them.

Multiple request-response calls to other machines (RPC)

- A client does several calls at the same time, each one by a different thread.
- It then waits until all results have been returned.
- Note: if calls are to different servers, we may have a linear speed-up.

Using threads at the server side

Improve performance

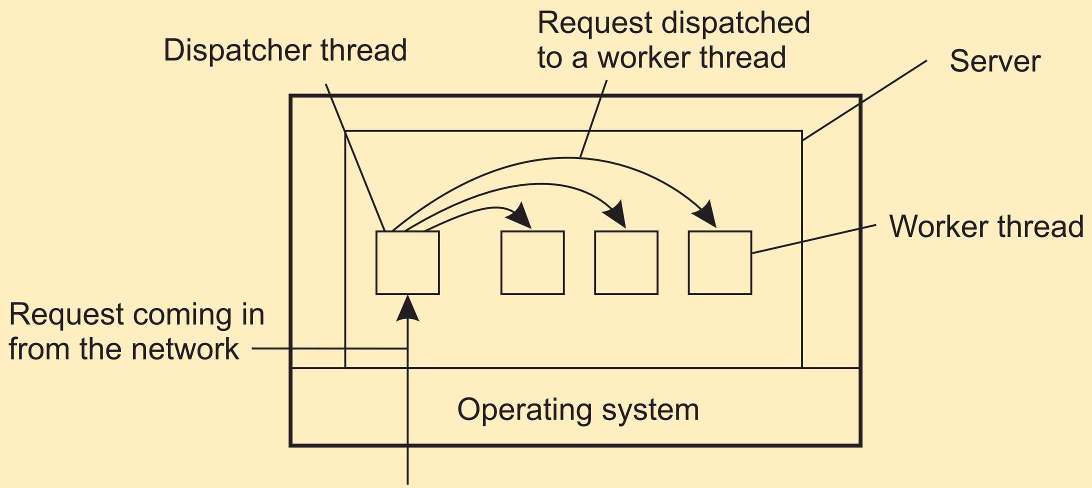
- Starting a thread is cheaper than starting a new process.
- Having a single-threaded server prohibits simple scale-up to a multiprocessor system.
- As with clients: hide network latency by reacting to next request while previous one is being replied.

Better structure

- Most servers have high I/O demands. Using simple, well-understood blocking calls simplifies the overall structure.
- Multithreaded programs tend to be smaller and easier to understand due to simplified flow of control.

Why multithreading is popular: organization

Dispatcher/worker model



Overview

Model	Characteristics
Multithreading	Parallelism, blocking system calls
Single-threaded process	No parallelism, blocking system calls
Finite-state machine	Parallelism, nonblocking system calls

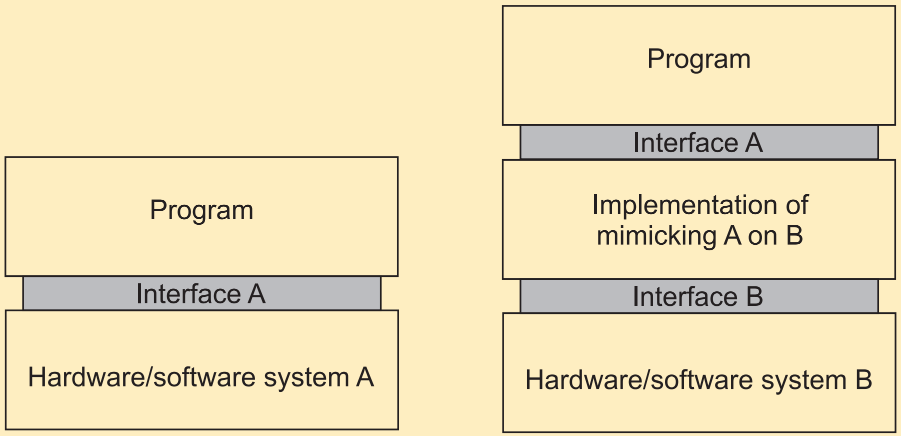
Virtualization

Observation

Virtualization is important:

- Hardware changes faster than software
- Ease of portability and code migration
- Isolation of failing or attacked components

Principle: mimicking interfaces



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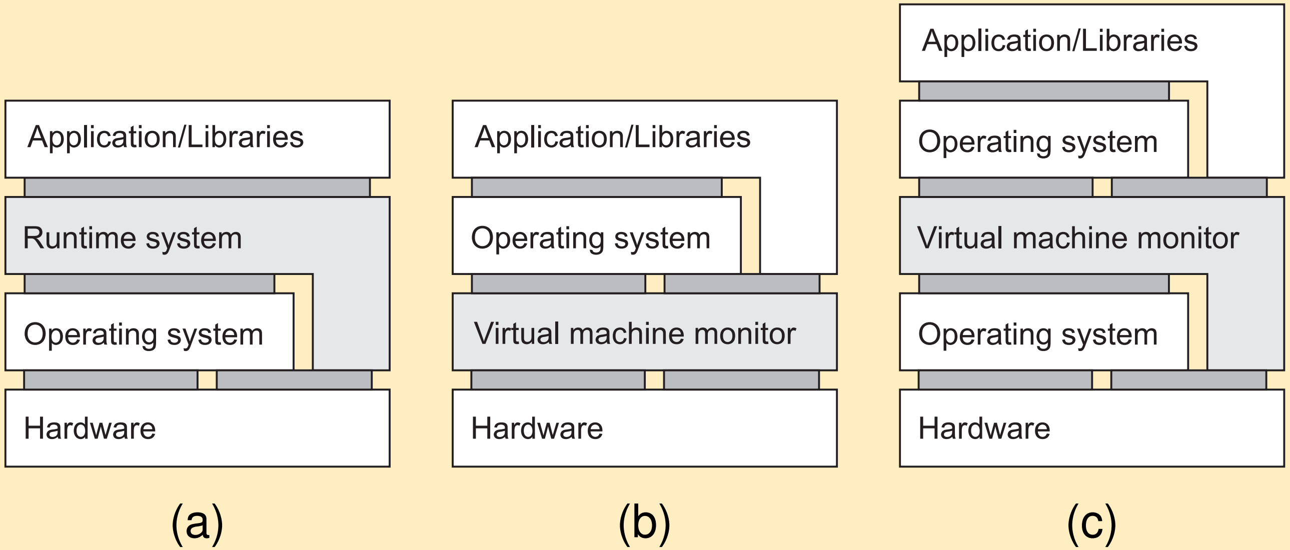
Mimicking interfaces

Four types of interfaces at three different levels

1. Instruction set architecture: the set of machine instructions, with two subsets:
   - Privileged instructions: allowed to be executed only by the operating system.
   - General instructions: can be executed by any program.
2. System calls as offered by an operating system.
3. Library calls, known as an application programming interface (API)

Ways of virtualization

(a) Process VM, (b) Native VMM, (c) Hosted VMM



Differences

(a) Separate set of instructions, an interpreter/emulator, running atop an OS.
(b) Low-level instructions, along with bare-bones minimal operating system
(c) Low-level instructions, but delegating most work to a full-fledged OS.

VMs and cloud computing

Three types of cloud services

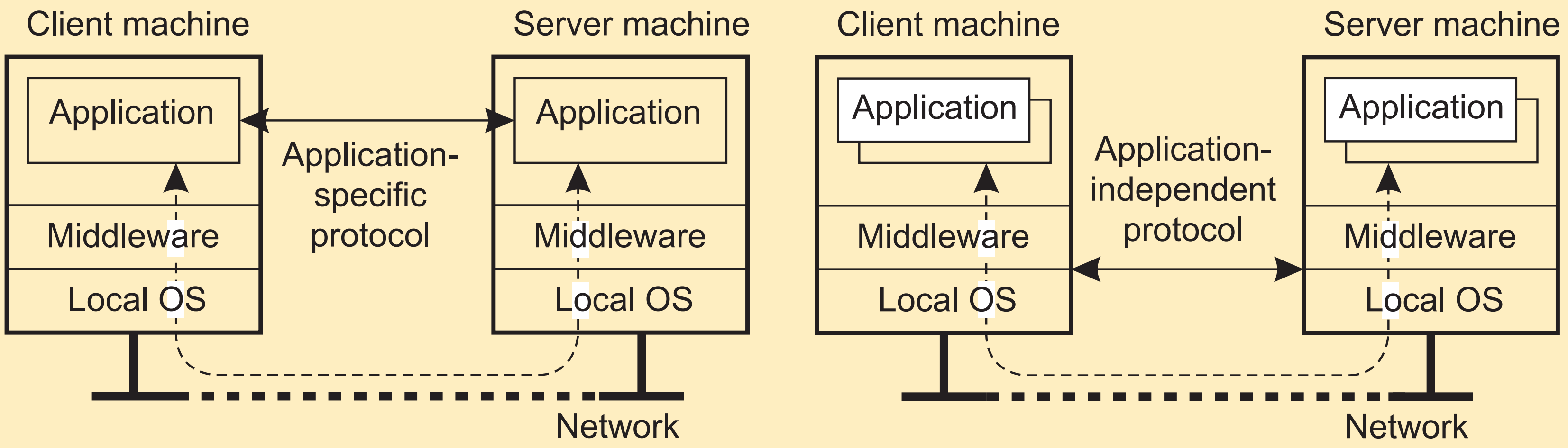
- Infrastructure-as-a-Service covering the basic infrastructure
- Platform-as-a-Service covering system-level services
- Software-as-a-Service containing actual applications

IaaS

Instead of renting out a physical machine, a cloud provider will rent out a VM (or VMM) that may possibly be sharing a physical machine with other customers ⇒ almost complete isolation between customers (although performance isolation may not be reached).

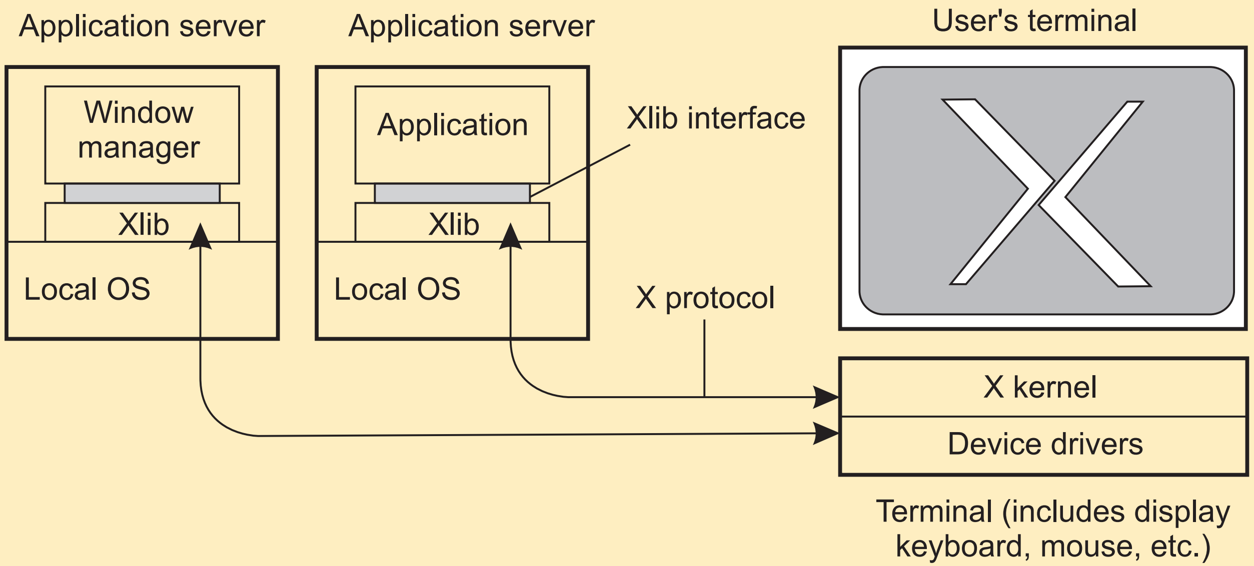
Client-server interaction

Distinguish application-level and middleware-level solutions



Example: The X Window system

Basic organization



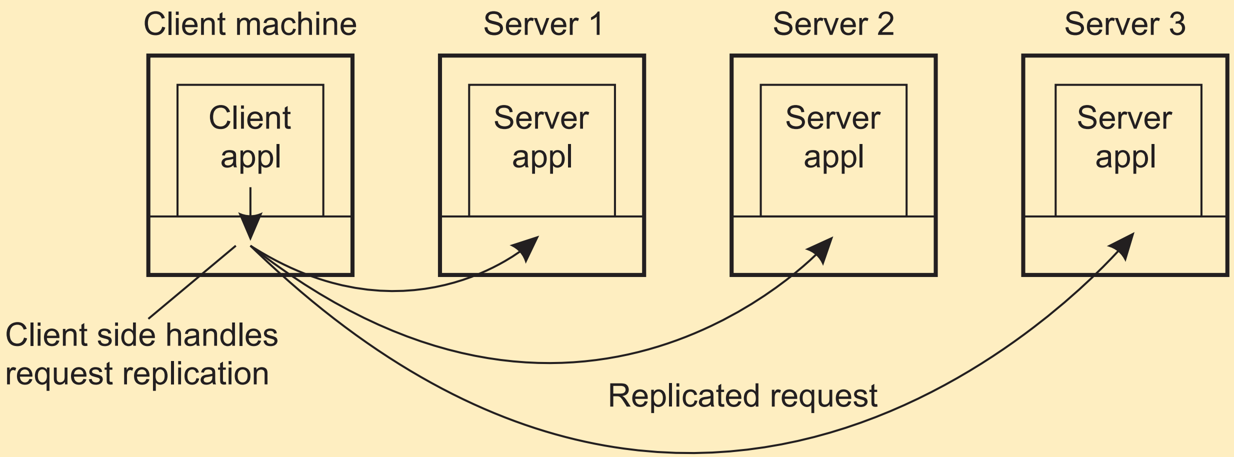
X client and server

The application acts as a client to the X-kernel, the latter running as a server on the client's machine.

Client-side software

Generally tailored for distribution transparency

- Access transparency: client-side stubs for RPCs
- Location/migration transparency: let client-side software keep track of actual location
- Replication transparency: multiple invocations handled by client stub:



- Failure transparency: can often be placed only at client (we're trying to mask server and communication failures).

Servers: General organization

Basic model

A process implementing a specific service on behalf of a collection of clients. It waits for an incoming request from a client and subsequently ensures that the request is taken care of, after which it waits for the next incoming request.

Concurrent servers

Two basic types

- Iterative server: Server handles the request before attending a next request.
- Concurrent server: Uses a dispatcher, which picks up an incoming request that is then passed on to a separate thread/process.

Observation

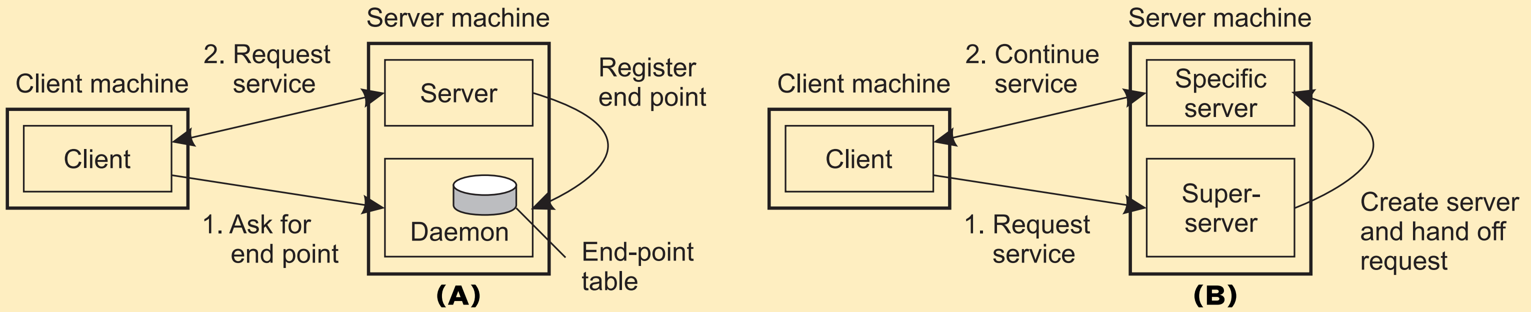
Concurrent servers are the norm: they can easily handle multiple requests, notably in the presence of blocking operations (to disks or other servers).

Contacting a server

Observation: most services are tied to a specific port

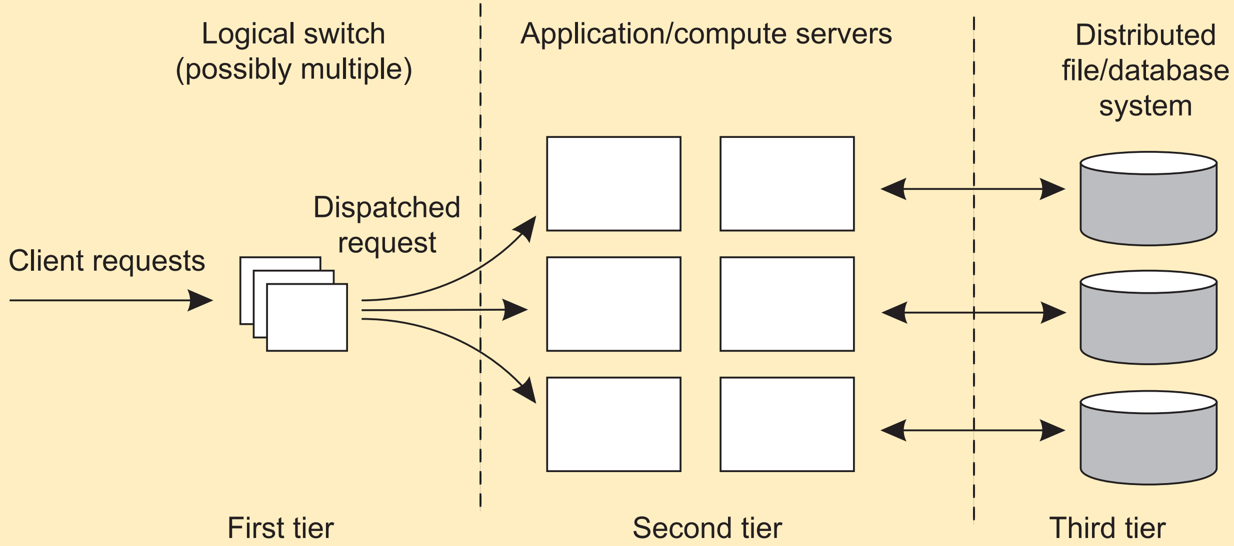
ftp-data	20	File Transfer [Default Data]
ftp	21	File Transfer [Control]
telnet	23	Telnet
smtp	25	Simple Mail Transfer
www	80	Web (HTTP)

Dynamically assigning an end point



Three different tiers

Common organization



Crucial element

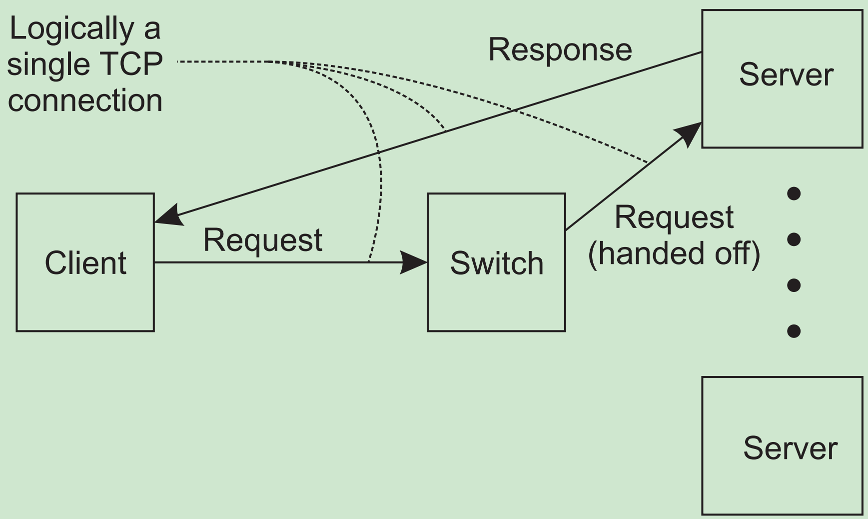
The first tier is generally responsible for passing requests to an appropriate server: request dispatching

Request Handling

Observation

Having the first tier handle all communication from/to the cluster may lead to a bottleneck.

A solution: TCP handoff

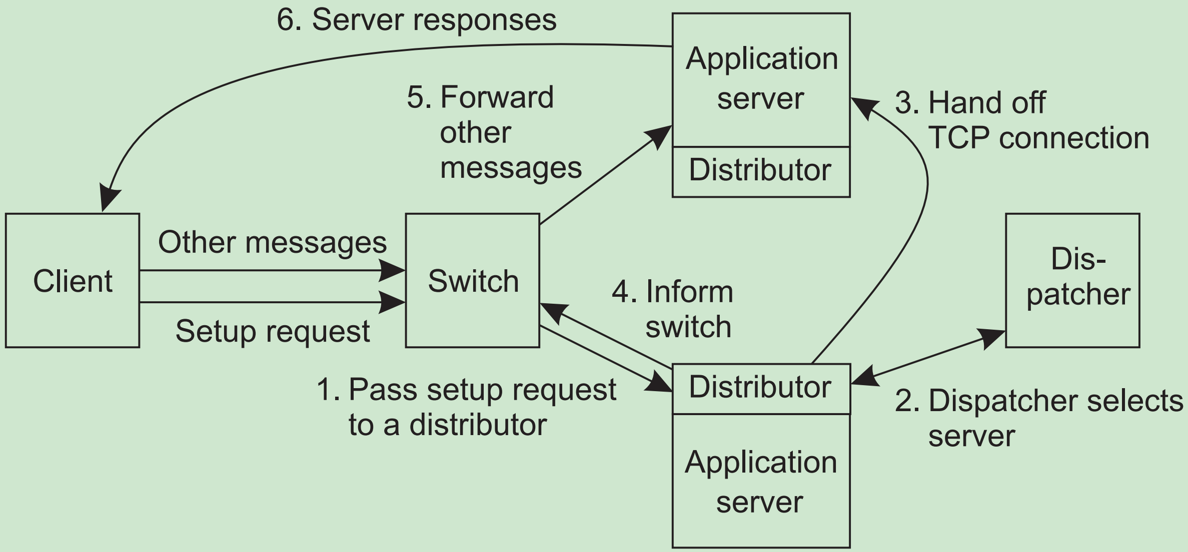


Server clusters

The front end may easily get overloaded: special measures may be needed

- Transport-layer switching: Front end simply passes the TCP request to one of the servers, taking some performance metric into account.
- Content-aware distribution: Front end reads the content of the request and then selects the best server.

Combining two solutions



When servers are spread across the Internet

Observation

Spreading servers across the Internet may introduce administrative problems. These can be largely circumvented by using data centers from a single cloud provider.

Request dispatching: if locality is important

Common approach: use DNS:

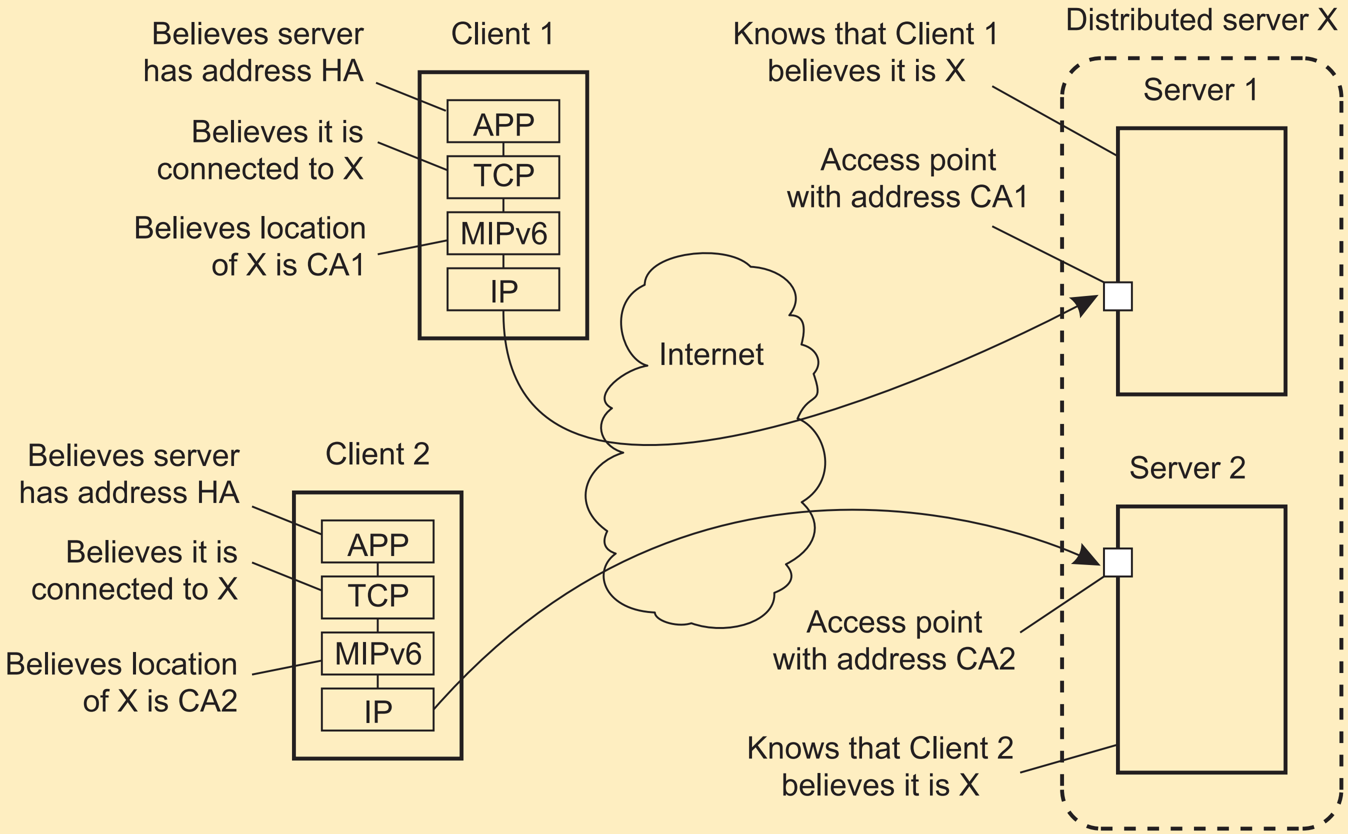
1. Client looks up specific service through DNS - client's IP address is part of request
2. DNS server keeps track of replica servers for the requested service, and returns address of most local server.

Client transparency

To keep client unaware of distribution, let DNS resolver act on behalf of client. Problem is that the resolver may actually be far from local to the actual client.

Distributed servers with stable IPv6 address(es)

Transparency through Mobile IP



Distributed servers: addressing details

Essence: Clients having MobileIPv6 can transparently set up a connection to any peer

- Client *C* sets up connection to IPv6 home address *HA*
- *HA* is maintained by a (network-level) home agent, which hands off the connection to a registered care-of address *CA*.
- *C* can then apply route optimization by directly forwarding packets to address *CA* (i.e., without the handoff through the home agent).

Collaborative distributed systems

Origin server maintains a home address, but hands off connections to address of collaborating peer ⇒ origin server and peer appear as one server.