Distributed Systems

13A. Distributed Systems: Goals & Challenges
13B. Distributed Systems: Communication
13H. Public Key Encryption

Goals of Distributed Systems

- scalability and performance
  - apps require more resources than one computer has
  - grow system capacity /bandwidth to meet demand
- improved reliability and availability
  - 24x7 service despite disk/computer/software failures
- ease of use, with reduced operating expenses
  - centralized management of all services and systems
  - buy (better) services rather than computer equipment
- enable new collaboration and business models
  - collaborations that span system (or national) boundaries
  - a global free market for a wide range of new services

the end of self-contained systems

- authentication
  - Active Directory, LDAP, Kerberos, …
- configuration and control
  - Active Directory, LDAP, DHCP, CIM/WBEM, SNMP, …
- external data services
  - CIFS, NFS, Andrew, Amazon S3, …
- remote devices
  - X11, web user interfaces, network printers
- even power management, bootstrap, installation
  - vPro, PXE boot, bootp, live CDs, automatic s/w updates

Peter Deutsch's "Seven Falacies of Network Computing"

1. network is reliable
2. no latency (instant response time)
3. available bandwidth is infinite
4. network is secure
5. network topology & membership are stable
6. network admin is complete & consistent
7. cost of transporting additional data is zero

Bottom Line: true transparency is not achievable

Heterogenous Interoperability

- heterogenous clients
  - different instruction set architectures
  - different operating systems and versions
- heterogenous servers
  - different implementations
  - offered by competing service providers
- heterogenous networks
  - public and private
  - managed by different orgs in different countries

Fundmental Building Blocks Change

- the old model
  - programs run in processes
  - programs use APIs to access system resources
  - API services implemented by OS and libraries
- the new model
  - clients and servers run on nodes
  - clients use APIs to access services
  - API services are exchanged via protocols
- local is a (very important) special case

Performance, Scalability, Availability

- old model – better components (4-40%/yr)
  - find and optimize all avoidable overhead
  - get the OS to be as reliable as possible
  - run on the fastest and newest hardware
- new better – better systems (1000x)
  - add more $150 blades and a bigger switch
  - spreading the work over many nodes is a huge win
    - performance – linear with/number of blades
    - availability – service continues despite node failures

Changing Paradigms

- network connectivity becomes "a given"
  - new applications assume/exploit connectivity
  - new distributed programming paradigms emerge
  - new functionality depends on network services
- applications demand new kinds of services:
  - location independent operations
  - rendezvous between cooperating processes
  - WAN scale communication, synchronization

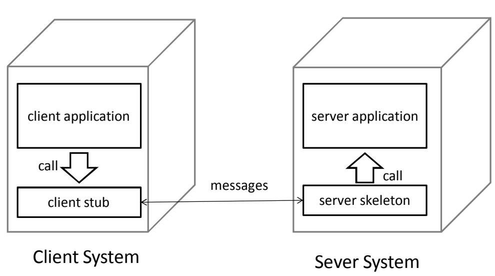
General Paradigm – RPC

- procedure calls – a fundamental paradigm
  - primary unit of computation in most languages
  - unit of information hiding in most methodologies
  - primary level of interface specification
- a natural boundary between client and server
  - turn procedure calls into message send/receives
- a few limitations
  - no implicit parameters/returns (e.g. global variables)
  - no call-by-reference parameters
  - much slower than procedure calls (TANSTAAFL)

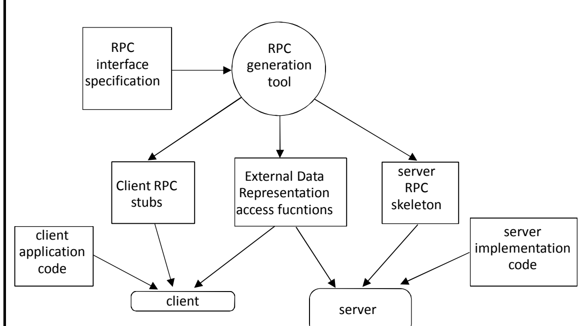
Remote Procedure Call Concepts

- Interface Specification
  - methods, parameter types, return types
- eXternal Data Representation
  - language/ISA independent data representations
  - may be abstract (e.g. XML) or efficient (binary)
- client stub
  - client-side proxy for a method in the API
- server stub (or skeleton)
  - server-side recipient for API invocations

Remote Procedure Calls – Data Flow



Remote Procedure Calls – Tool Chain



(RPC – Key Features)

- client application links against local procedures
  – calls local procedures, gets results
- all rpc implementation is inside those procedures
- client application does not know about RPC
  – does not know about formats of messages
  – does not worry about sends, timeouts, resents
  – does not know about external data representation
- all of this is generated automatically by RPC tools
- the key to the tools is the *interface specification*

The Interoperability Challenge

- S/W, APIs and protocols evolve
  – to embrace new requirements, functionality
- A single node is running a single OS release
  – all s/w can be upgraded at same time as OS
- A distributed system is unlikely homogenous
  – rolling upgrades do one server at a time
  – newly added servers may be up/down-rev
  – we may have no control over client s/w versions
- we must ensure they all "play well" together

Ensuring Interoperability

1. restricted evolution
   – all changes must be upwards compatible
2. compensation (run-time restriction)
   – all sessions begin with version negotiation
3. better tools that embrace polymorphism
   – every agent speaks his own protocol version
   – RPC language and tools are version-aware
     - messages are un-marshaled as each client expects
     - default behaviors are based on older expectations
   – equally applicable to messages and at-rest data

Extensible Data Representations

- Upwards compatible serialized object formats
  – platform independent data representations
  – client-version sensitive translation
    - old clients never see new-version fields
    - new clients infer upwards compatible defaults
- Example: Google Protocol Buffers
  – very efficient translation
  – applicable to both protocols and persisted data
  – supports many representations (e.g. binary, json)
  – has adaptors for many languages (e.g. C, python)

RPC is not a complete solution

- client/server binding model
  – expects to be given a live connection
- threading model implementaiton
  – a single thread service requests one-at-a-time
  – numerous one-per-request worker threads
- failure handling
  – client must arrange for timeout and recovery
- higher level abstractions
  – e.g. Microsoft DCOM, Java RMI, DRb, Pyro

Evolving Interaction Paradigms

- HTTP is becoming the preferred transport
  – well supported, tunnels through firewalls
- Simple Object Access Protocol (SOAP)
  – HTTP transport of XML encoded RPC requests
  – options for other transports and encodings
  – supports non-RPC interactions (e.g. transactions)
- REpresentational State Transfer (REST)
  – stateless, scalable, cacheable, layerable
  – operations limited to Create/Read/Update/Delete

Sample SOAP Request

```xml
<?xml version="1.0"?>
<soap:Envelope xmlns:soap="http://www.w3.org/2003/05/soap-envelope">
  <soap:Header>
  </soap:Header>
  <soap:Body>
    <m:GetStockPrice xmlns:m="http://www.example.org/stock/Surya">
      <m:StockName>IBM</m:StockName>
    </m:GetStockPrice>
  </soap:Body>
</soap:Envelope>
```


Sample REST (json) Request

```json
{
  "username" : "my_username",
  "password" : "my_password",
  "validation-factors" : {
     "validationFactors" : [
       {
          "name" : "remote_address",
          "value" : "127.0.0.1"
       }
     ]
  }
}
```


Marshal (and un-marshal)

- English

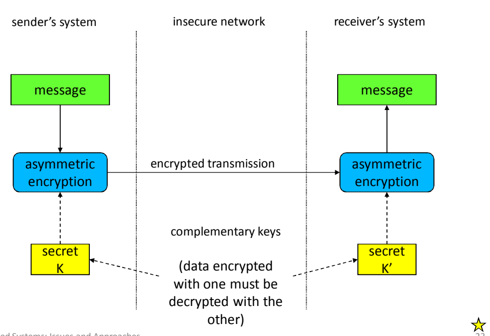
  to arrange or assemble a group into order
  - usually a group of people or soldiers
  - also assembling *devices* into a *coat of arms*
- Computer Science

  transforming the in-memory representation of an object into a suitable format for storage or transmission

Asymmetric Cryptosystems

- Encryption and decryption use different keys
  - $C = E(K_E, P)$
  - $P = D(K_D, C)$
  - $P = D(K_D, E(K_E, P))$
- Often works the other way, too
  - $C = E(K_D, P)$
  - $P = D(K_E, C)$
  - $P = D(K_D, E(K_E, P))$
- Public Key (PK) encryption is such a system
  - K_E is called the *public key*, K_D is called the *private key*
  - it is very difficult to infer K_D from *D, E, C, P* and K_E

Asymmetric Encryption (public key)



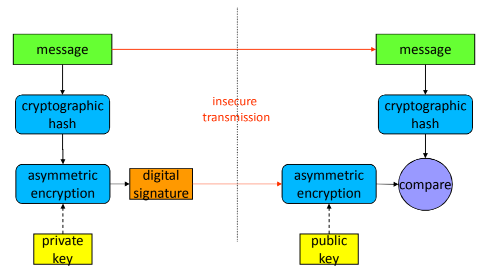
(Public Key Encryption)

- an asymmetric (two key) encryption technique
  - one key is private – (not shared) only key owner knows it
  - one key is public – it is advertised to the entire world
- it can be used to implement "your eyes only" privacy
  - encrypt a message with the recipient's public key
  - the message can only be decrypted with his private key
- it can be used to implement guaranteed signatures
  - sender encrypts message with his own private key
  - if it decrypts w/sender's public key, it must be from sender
- these can be combined for authentication + privacy

Example Public Key Ciphers

- RSA
  - the most popular public key algorithm
  - used on pretty much everyone's computer
- Elliptic curve cryptography
  - an alternative to RSA
  - tends to have better performance
  - not as widely used or studied

Digital Signatures



(Signing a message)

- encrypting a message with private key signs it
  - only you could have encrypted it, it must be from you
  - it has not been tampered with since you wrote it
- encrypting everything w/private key is a bad idea
  - if use a key too much, someone will eventually crack it
  - asymmetric encryption is extremely slow
- no need to encrypt whole message w/private key
  - compute a cryptographic hash of your message
  - encrypt the cryptographic hash with your private key
  - faster and safer than encrypting whole message

Using Digital Signatures

- much better than ink signatures or fingerprints
  - uniquely identify the document signer
  - uniquely identify the document that was signed
  - signature cannot be copied onto another document
- we know document has not been tampered with
  - we can recompute the cryptographic hash at any time
  - confirm it matches message the sender signed
  - sender cannot later claim not to have signed message
- digitally signed contracts can be legally binding
  - several states have passed such legislation

Can we trust public keys?

- if I have a public key
  - I can authenticate received messages
  - I know they were sent by the owner of the private key
- but how do I know who that person is?
  - can I be sure who a public key belongs to?
  - how do I know that this is really my bank's public key?
  - could some swindler have sent me his key instead?
- I would like a certificate of authenticity
  - a digital Notary stamp
  - certifying who the real owner of a public key is

Public Key Certificates

```
Certificate:
  Data:
    Version: v3; Serial Number: 3;
    Issuer: OU=Ace Certificate Authority, O=Ace Industry, C=US
    Validity: Not  After: Sun Oct 17 18:36:25 1999
    Subject: CN=Jane Doe, OU=Finance, O=Ace Industry, C=US
    Subject Public Key Info: Algorithm: PKCS #1 RSA Encryption
      Public Key: Modulus:
          00:ca:fa:79:98:8f:19:f8:d7:de:e4:49:80:48:e6:2a:2a:86:
          ...
  Signature:
    Algorithm: PKCS #1 MD5 With RSA Encryption
    Signature:
      6d:23:af:f3:d3:b6:7a:df:90:df:cd:7e:18:6c:01:69:8e:54:65:fc:06:
      ...
```

(What Is a PK Certificate?)

- Essentially a data structure
  - name and description of an actor
  - public key belonging to that actor
  - validity/expiration information
- Signed by someone I trust
  - whose public key I already have
  - a digital Notary Public
- Testifying that the actor owns the public key
  - and (by implication) the matching private key

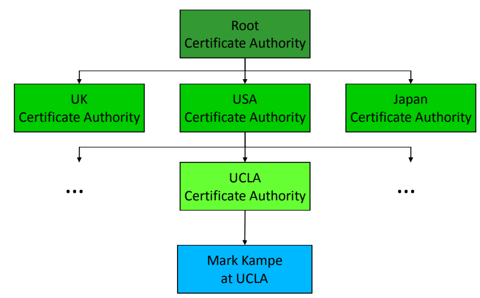
Using Public Key Certificates

- if I know public key of the authority who signed it
  - I can validate the signature is correct
  - I can tell the certificate has not been tampered with
- if I trust the authority who signed the certificate
  - I can trust they authenticated the certificate owner
  - e.g. we trust drivers licenses and passports
- but first I must know and trust signing authority
  - everybody knows and trusts RSA as an authority
  - does that mean that only RSA can sign certificates?

Delegated Authority

- I can accept certificates from a known authority
  - not practical for one authority to issue all certificates
  - how to validate certificates from unknown authority
- what if he has a certificate
  - that is signed by an authority I know and trust
  - that authorizes him to issue certificates
- if I trust RSA, I should also trust their "delegates"
  - perhaps I can also trust people they delegate
  - but I would need to see the <u>entire chain</u> of certificates

Certificate Authority Hierarchy



A Chicken and Egg Problem

- certificate is a formal introduction to a new partner
  - I can trust he is who he claims to be
  - if I can validate the certificate
  - by following the chain of delegated trust
- How do I trust the authority at the end of the chain?
- Ultimately through some other mechanism
  - OS or browser comes with an initial set of certificates
  - hand delivered (as in our IOT security project)
  - down-loaded, over a secure channel, from trusted site
  - you decide to accept a new certificate

Assignments

- For next lecture
  - Arpaci C48: NFS
  - Leases
  - Distributed Consensus
  - Two-Phase & Three-Phase Commits
  - Authentication Services
- Lab
  - Project 3B

Supplementary Slides

new view of "system architecture"

- customers pay for services
  - we design and build systems to provide services
- services are built up from protocols
  - service is delivered to customers via a network
  - service is provided by collaborating servers
  - servers are commissioned/controlled by network
- the fundamental unit of service is a node
  - provides defined services over defined protocols
  - language, OS, ISA are mere implementation details

Centralized System Management

- single point of management for all systems
  - ensure consistent service configuration
  - eliminate problems with mis-configured clients
- zero client-side administration
  - plug in a new client, and it should just work
  - reduced (per client) costs of support
- uniform & ubiquitous computer services
  - all data and services available from all clients
  - global authentication and resource domain

Centralized Services and Servers

- quality and reliability of service
  - guaranteed to be up 24x7
  - performance monitored, software kept up-to-date
  - regular back-ups taken
- price performance
  - powerful servers amortized over many clients
- ease of use
  - no need to install and configure per client services
  - services are available from any client

System Initialization

- Dynamic Host Configuration Protocol
  - automatic IP address assignment (static or dynamic)
  - automatic network configuration (subnet, gateway)
  - server discovery (domain and other services)
  - locate an appropriate network boot server
- Trivial File Transfer Protocol
  - anonymous UDP file transfer protocol
  - used to load boot images over the network

System Configuration

- Domain Name Service
  - host-name to IP address resolution
- Lightweight Directory Access Protocol
  - domain configuration database
    - associates attributes with "distinguished names" (keys)
      - information about users, devices, services, etc
- Active Directory
  - Microsoft domain configuration database
    - supported by its own APIs
    - accessible through LDAP

System Management

- Simple Network Management Protocol
  - defines standard Management Information Bases
    - get/set operations for status and control
    - devices can generate asynchronous TRAPs
- Common Information Model
  - defines standard schemas and object models
    - Web Based Enterprise Management (XML binding)
    - Windows Management Instrumentation (COM binding)
- System Logging
  - forwarding event messages to log server

the Rise of "Middle-ware"

- old model – the OS was the platform
  - applications are written for an Operating System
  - OS implements resources to enable applications
- new model – the OS enables the platform
  - applications are written to a middle-ware layer
    - e.g. Enterprise Java Beans, Component Object Model, etc.
  - object management is user-mode and distributed
    - e.g. CORBA, SOAP
  - OS APIs less relevant to applications developers
    - the network <u>is</u> the computer

Remote File Access

- Network File System (NFS)
  - originated at Berkeley, peer-to-peer file sharing
- Common Internet File System (aka SMB)
  - originated at Microsoft, remote file access sessions
- Special Purpose NAS products
  - NAS virtualization
  - High Performance Computing
  - High Bandwidth Streaming
  - Information Lifecycle Management

Security and Licensing

- Kerberos
  - encryption based authentication/work-ticket server
- NT LAN Manager Authentication
  - challenge/response authentication
- Key Servers and Public Key Infrastructure
  - storage and retrieval of public key certificates
- License Managers
  - run-time validation of license authenticity

Mail & Messaging

- Outgoing mail servers
  - know how to route outgoing mail for delivery
  - Simple Mail Transfer Protocol
- Incoming mail servers
  - available 24x7 to receive and view mail, backed up
  - Post Office Protocol, Internet Mail Access Protocol
- Internet Relay Chat servers
  - form the backbone for chat traffic
  - Internet Relay Chat Protocol (or something like it)

Service Discovery

- Service Location Protocol
  - resource/service registration and discovery protocol
- Object Reference Brokers and IIOP
  - registry for object implementations
  - match maker for remote object references
- Jini/JDMK
  - Java tools to find services and protocol adaptors

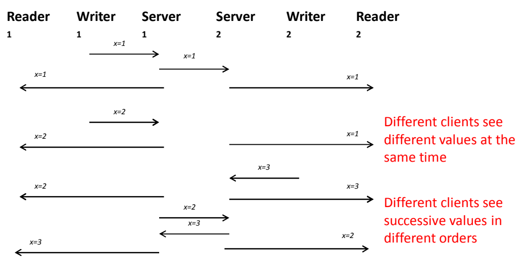
Advanced Features – IP Multiplexing

- large servers may need heroic bandwidth
  - more than one interface can deliver
  - perhaps more than one wire can carry
- put multiple interfaces on multiple sub-nets
- exploit them with smarter IP routing
  - routing should always pick the quickest route
  - both subnets are known to lead to the same place
  - IP can look at queue lengths, and pick the shorter
  - or it could just "round-robin" through the interfaces
- getting input redirected is a harder problem

Advanced Features – Quality of Service

- guarantee apps a fixed share of bandwidth
- very useful for time-critical messages
  - real-time telemetry
  - streaming video
- implement with a scheduling module
  - plumbed between IP and Generic LAN Driver
  - observes queues and schedules packets for drivers
- result: key applications less sensitive to overload
- caveat: QoS is an end-to-end problem
  - it must be solved all along the line

Distributed Temporal Separation



1. The system does not have a scalar state. State is a vector.
2. There is no total ordering; There are only partial orderings.