

Distributed Systems Modelling Distributed Systems

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Contents

- The software architecture of a distributed system
- The run-time architecture
- The interaction model
- The failure model



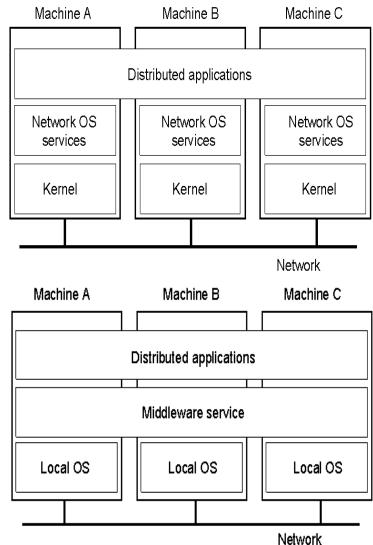
The software architecture of a distributed system

Network OS based

- The network OS provides the communication services
- Diferent machines may have different network OSes
- Masking platform differences is up to the application programmer

Middleware based

- The middleware provides advanced communication, coordination, and administration services
- It masks most of the platform differences





Middleware: A functional view

- Middleware provides "business-unaware" services through a standard API, which raises the level of the communication activities of applications
- Usually it provides
 - Communication and coordination services
 - Synchronous and asynchronous
 - Point-to-point or multicast
 - Masking differences in the network OS
 - Special application services
 - Distributed transaction management, groupware and workflow services, messaging services, notification services, ...
 - Management services
 - Naming, secutiry, failure handling, ...



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The run-time (system) architecture of a distributed system

- Identifies the classes of components that build the system, the various types of connectors, and the data types exchanged at run-time
- Modern distributed systems often adopt one among a small set of well known *architectural styles*
 - Client-server
 - Service Oriented
 - REST
 - Peer-to-peer
 - Object-oriented
 - Data-centered
 - Event-based
 - Mobile code
 - CREST



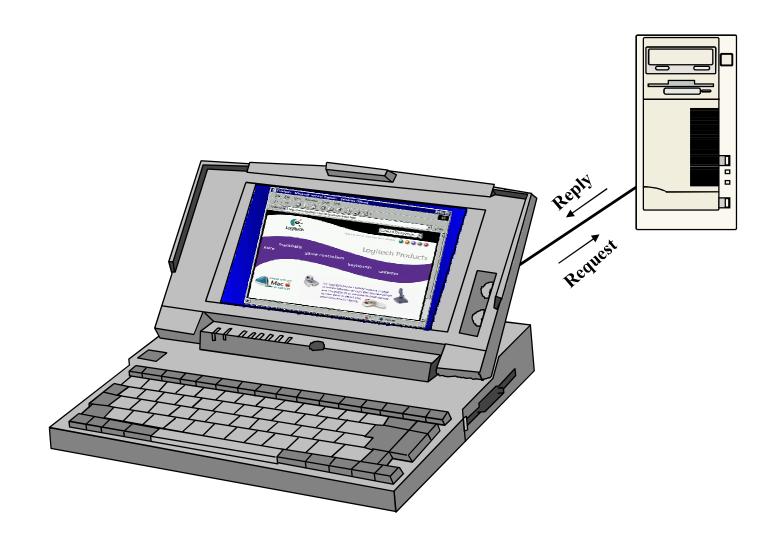
Client-server

- The most common architectural style today
- Components have different roles
 - Servers provide a set of services through a well defined
 API
 - They are passive (just wait for client invocations)
 - Users access those services through *clients*
 - Communication is message based (or RPC)



The Web is a client-server application

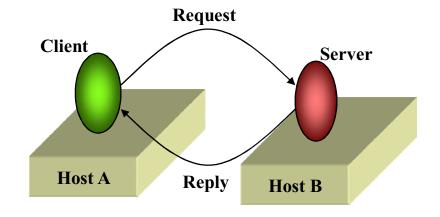
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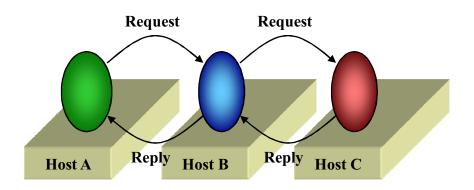




Tiers

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- Often servers operate by taking advantage of the services offered by other distributed components
 - In such case we have a threetiered client-server architecture
- The services offered by a distributed application can be partitioned in three classes
 - User interface services,
 application services, storage
 services
- Multi-tiered client-server
 applications can be classified
 looking at the way such services
 are assigned to the different tiers

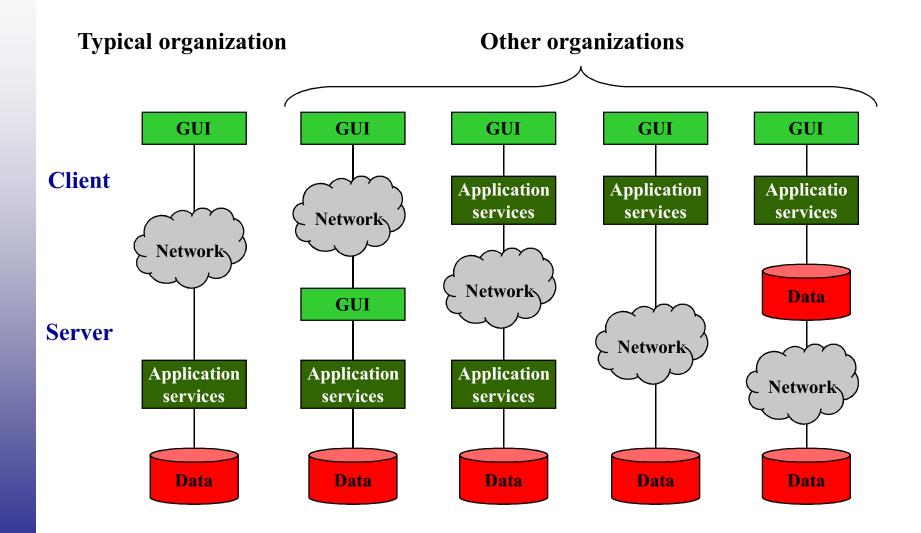






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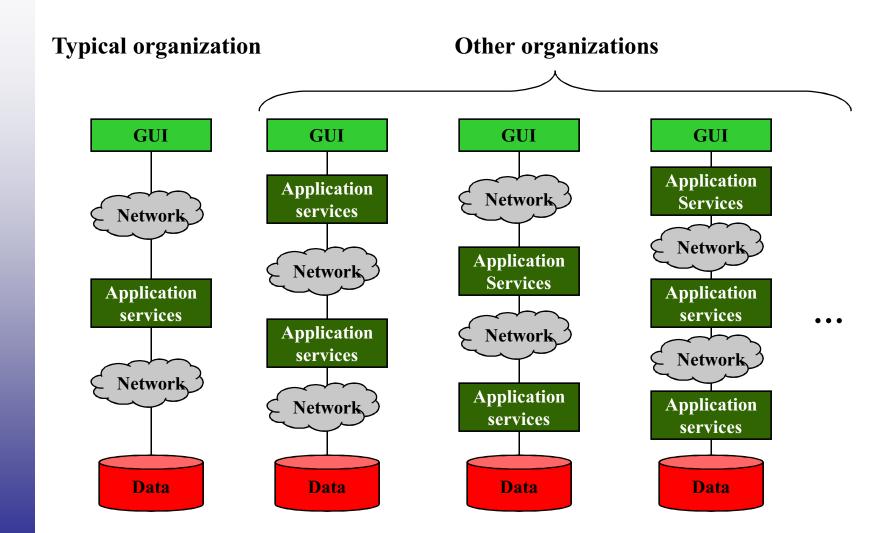
Two tiered architectures





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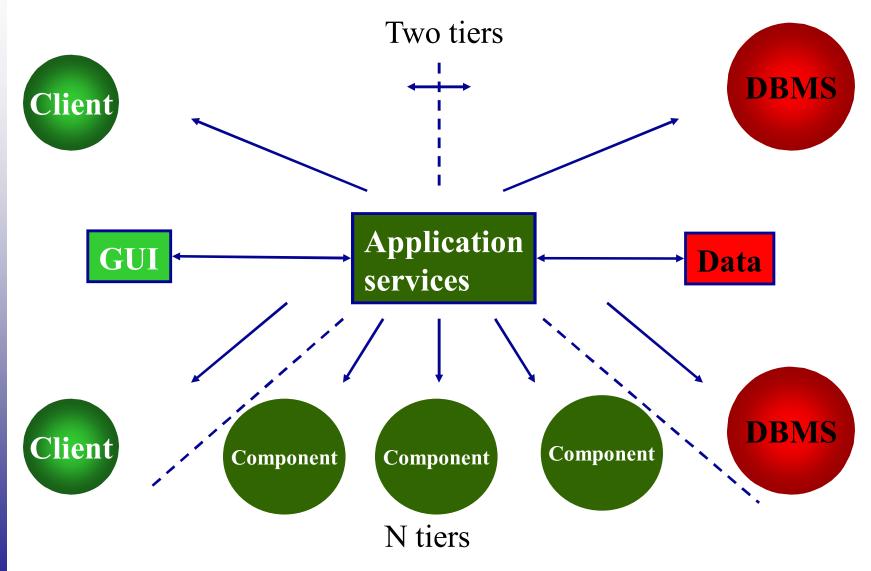
Three-tiered architectures





From two to multi-tiered architectures

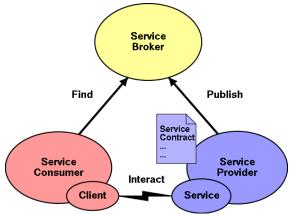
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The Service Oriented Architecture

- Built around the concepts of *services*, *service providers*, *service consumers*, *service brokers*
 - Services represent loosely coupled units of functionality...
 - exported by service providers
 - Brokers hold the description of available services to be searched by interested consumers...
 - ...which bind and invoke the services they need
 - Orchestration is the process of invoking a set of services in an ad-hoc workflow to satisfy a given goal
- Several incarnations
 - OSGI (Open Grid Services Infrastructure, JXTA, Jini, Web Services





Web Services

- Web Service: "a software system designed to support interoperable machine-to-machine interaction over a network" [W3C]
- Its interface is described *WSDL* (Web Service Description Language)
 - It includes the set of operations exported by the web service
- Web service operations are invoked through *SOAP*, a protocol, based on XML, which defines the way messages (operation calls) are actually exchanged
 - Usually based on HTTP but other transport protocols can be used
- *UDDI* (Universal Description Discovery & Integration) describes the rules that allows web services to be exported and searched through a *registry*



The REST style

- REpresentational State Transfer (REST) is both:
 - A (nice) way to describe the web
 - by Roy Thomas Fielding, one of the authors of HTTP/1.1, co-founder and member of the Apache Software Foundation
 - A set of principles that define how Web standards are supposed to be used
 - Which often differs quite a bit from what many people actually do
- Key goals of REST include:
 - Scalability of component interactions
 - Generality of interfaces
 - Independent deployment of components
 - Intermediary components to reduce latency, enforce security and encapsulate legacy systems



REST: Main constraints

- Interactions are client-server
- Interactions are stateless
 - State must be transferred from clients to servers
- The data within a response to a request must be implicitly or explicitly labeled as cacheable or non-cacheable
 - The ability of caching data is key to provide scalability
- Each component cannot "see" beyond the immediate layer with which they are interacting
 - REST is layered
- Clients must support code-on-demand
 - This is an optional constraint (more on this later)
- Components expose a uniform interface



REST: Uniform interface constraints

- The uniform interface exposed by components must satisfy four constraints:
 - Identification of resources
 - Each resource must have an id (usually an URI) and everything that have an id is a valid resource (including a service)
 - Manipulation of resources through representations
 - REST components communicate by transferring a representation of a resource in a format matching one of an evolving set of standard data types (e.g., XML), selected dynamically based on the capabilities or desires of the recipient and the nature of the resource
 - Whether the representation is in the same format as the raw resource, or is derived from the resource, remains hidden behind the interface
 - A representation consists of data and metadata describing the data
 - Self-descriptive messages
 - Control data defines the purpose of a message between components, such as the action being requested or the meaning of a response
 - It is also used to parameterize requests and override the default behavior of some connecting elements (e.g., the cache behavior)
 - Hypermedia as the engine of application state
 - Clients move from a state to another each time process a new representation, usually linked to other representation through hipermedia links



Peer-to-peer

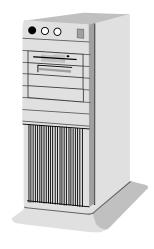
- In a peer-to-peer applications all components play the same role
 - There is no distinction between clients and servers
- Why p2p
 - Client-server does not scale well
 - Due to the centralization of service provision and management
 - The server is also a single point of failure
 - P2P leverages off the increased availability of broadband connectivity and processing power at the end-host to overcome such limitations
- P2P promotes the sharing of resources and services through direct exchange between peers
 - Resources can be:
 - Processing cycles (SETI@home)
 - Collaborative work (ICQ, Skype, Waste)
 - Storage space (Freenet)
 - Network bandwidth (ad hoc networking, internet)
 - Data (most of the rest)

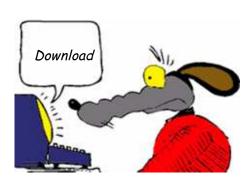


Why P2P is different









Fundamental difference:

"Take advantage of resources at the edges of the network" (Clay Shirky, O'Reilly)

- What's changed:
 - End-host resources have increased dramatically
 - Broadband connectivity now common



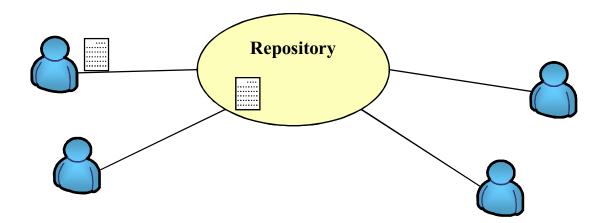
Object-Oriented

- The distributed components encapsulate a data structure providing an API to access and modify it
 - Each component is responsible for ensuring the integrity of the data structure it encapsulates
 - The internal organization of such data structure is hidden to the other components (who may access it only through the API mentioned above)
- Components interact through RPC
- Its a "peer to peer" model
 - But its often used to implement client-server applications
- Pros
 - Information hiding hides complexity in accessing/managing the shared data
 - Encapsulation plus information hiding reduce the management complexity
 - E.g., the objects that build the server may be moved at run-time to share the load
 - Objects are easy to reuse among different applications
 - Legacy components can be wrapped within objects and easily integrated in new applications



Data-centered

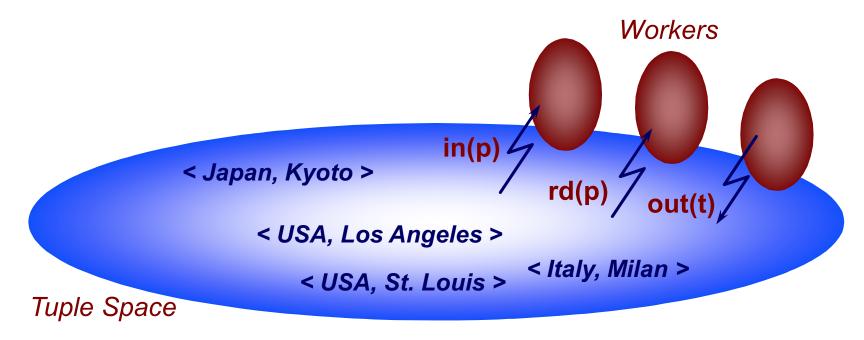
- Components communicate through a common (usually passive) repository
 - Data can be added to the repository or taken (moved or copied) from it
- Communication with the repository is (usually) through RPC
- Access to the repository is (usually) synchronized





Linda and tuple spaces

- Data sharing model proposed in the 80s by Carriero and Gelernter, mostly used for parallel computation
- Recently revitalized in the context of distributed computing
 - E.g., IBM TSpaces, Sun JavaSpaces, GigaSpaces
- Communication is persistent, implicit, content-based, generative
- High degree of decoupling





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Linda in a nutshell

- Data is contained in ordered sequences of typed fields (tuples)
- Tuples are stored in a persistent, global shared space (tuple space)
- Standard operations:
 - **out**(*t*): writes the tuple *t* in the tuple space
 - rd(p): returns a copy of a tuple matching the *pattern* (or *template*) p, if it exists; blocks waiting for a matching tuple otherwise
 - If many matching tuples exist, one is chosen non-deterministically
 - in(p): like rd(p), but withdraws the matching tuple from the tuple space
 - Some implementations provide also an **eval**(*a*), which inserts the tuple generated by the execution of a process *a*
- Many variants:
 - Asynchronous, non-blocking primitives (probes): rdp(p) and inp(p)
 - Return immediately a null value if the matching tuple is not found
 - Bulk primitives: e.g., rdg(p)
 - **–** ...
- Some of the non-standard primitives have non-trivial distributed implementations
 - E.g., if atomicity is to be preserved, probes require a distributed transaction



Architectural issues

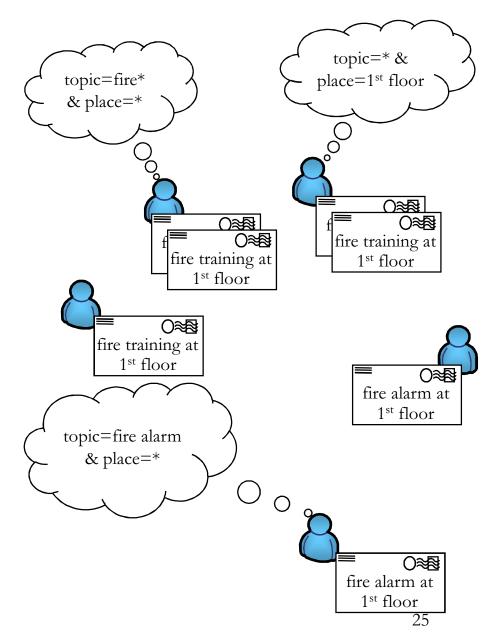
- The tuple space model is not easily scaled on a wide-area network
 - How to store/replicate tuples efficiently
 - How to route queries efficiently
- The model is only proactive
 - Processes explicitly request a tuple query
 - reactive/asynchronous behavior must implemented with an extra process and a blocking operation
- As a consequence, commercial implementations:
 - Provide only client access to a server holding the tuple space
 - Instead of a fully distributed, decentralized implementation
 - Introduce reactive primitives
 - e.g., **notify** allows to register a listener, invoked when a matching tuple is written



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Event-based

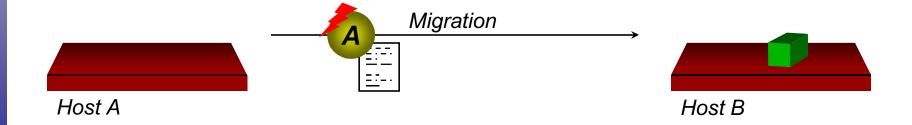
- Components collaborate by exchanging information about occurrent *events*. In particular:
 - Components *publish* notifications about the events
 they observe, or
 - they subscribe to the events they are interested to be notified about
- Communication is:
 - Purely message based
 - Asynchronous
 - Multicast
 - Implicit
 - Anonymous





Mobile code

- A style based on the ability of relocating the components of a distributed application at run-time
 - Only the code or both the code and the state
- Different models depending on the original and final location of resources, know-how (the code) and computational components (including the state of execution)





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Mobile code paradigms

Remote evaluation **Client-Server** PLEASE, MAKE ME A CHOCOLATE CAKE. HERE IS THE RECIPE: PLEASE, MAKE ME TAKE TWO EGGS. A CHOCOLATE CAKE Request Site A Site B Site B Site A PLEASE, TELL ME THE RECIPE HERE I AM! CAN I USE YOUR OVEN? Reauest Site A Site B Site A Site B

Code on demand

Mobile agent

Distributed systems: Modelling distributed systems



Mobile code technologies

- *Strong mobility* is the ability of a system to allow migration of both the code and the execution state of an executing unit to a different computational environment
 - Very few systems (usually research based) provide it
- Weak mobility is the ability of a system to allow code movement across different computational environments
 - Provided by several mainstream systems including Java,
 Net, the Web



Mobile code in practice

Pros

- The ability to move pieces of code (or entire components) at runtime provides a great flexibility to programmers
 - New versions of a component can be uploaded at run-time without stopping the application
 - Existing components can be enriched with new functionalities
 - New services can be easily added
 - Existing services can be adapted to the client needs

Cons

Securing mobile code applications is a mess



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CREST: REST meets mobile code

- REST is not sufficient to describe complex web 2.0 applications
 - E.g., those enabled by AJAX
- CREST (Computational REST) joins together the concepts of REST with mobile code
- Instead of "representations" interacting parties exchange "computations"
 - I.e., closures and continuations
- CREST axioms
 - A resource is a locus of computations named by an URL
 - The representation of a computation is an "expression" plus metadata to describe it
 - All computations are context-free
 - Only a few primitive operations are always available, but additional perresource and per-computation operations are also encouraged
 - The presence of intermediaries is promoted



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Distributed algorithms

- Traditional programs can be described in terms of the algorithm they implement
 - Steps are strictly sequential and (usually) process execution speed influence performance, only
- Distributed systems are composed of many processes, which interact in complex ways
- The behaviour of a distributed system is described by a distributed algorithm
 - A definition of the steps taken by each process, including the transmission of messages between them
- The behavior of a distributed system is influenced by several factors:
 - The rate at which each process proceeds
 - The performance of the communication channels
 - The different clock drift rates



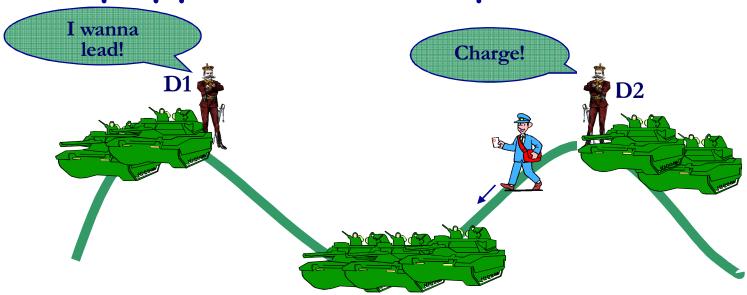
Interaction model

- To formally analyze the behavior of a distributed system we must distinguish (at least in principle) between:
 - Synchronous distributed systems
 - The time to execute each step of a process has known lower and upper bounds
 - Each message transmitted over a channel is received within a known bounded time
 - Each process has a local clock whose drift rate from real time has a known bound
 - Asynchronous distributed systems
 - There are no bounds for process execution speeds, message transmission delays, clock drift rates
- Any solution that is valid for an asynchronous distributed system is also valid for a synchronous one (but the vice versa is clearly false)



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The pepperland example



- The pepperland divisions are safe as long as they remain in their encampments
- If both charge at the same time they win, otherwise they loose
- Generals need to agree on:
 - Who will lead the charge
 - When the charge will take place
- We consider the case when messengers are able to walk from an hill to another without being captured by the enemies



The pepperland example

- Even in asynchronous pepperland it is possible to agree on who will lead the charge
 - How?
- Charging together is a different issue
 - It is not possible in asynchronous pepperland
 - If the leader sends a messenger to the other general saying "charge!" the messenger may take three hours or just five minutes to reach the other general
 - Also differences on each division's clock do not allow strategies based on sending a message with the time to charge
 - In synchronous pepperland it is possible to determine the maximum difference between charge times
 - Let min and max be the range of message transmission times
 - The leader sends a message "charge!", wait min minutes then charge
 - On receiving the "charge!" message the other general immediately charge
 - The second division may charge later then the first one but no more that (maxmin) minutes
 - If we know that the charge will last longer then the victory is guaranteed



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Failure model

- Both processes and communication channels may fail
- The failure model defines the ways in which failure may occur to provide a better understanding of the effects of failures
- We distinguish between
 - Omission failures
 - Processes: fail stop (other processes may detect certainly the failure) vs. Crash
 - Channels: send omission, channel omission, receive omission
 - Byzantine (or arbitrary) failures
 - Processes: may omit intended processing steps or add more
 - Channels: message content may be corrupted, non-existent messages may be delivered, or real messages may be delivered more than once
 - Timing failures (apply to synchronous systems, only)
 - Occur when one of the time limits defined for the system is violated



Failure detection in pepperland

- How to detect if one of the two divisions has been attacked and defeated by the enemies?
- Easy in synchronous pepperland:
 - Each division periodically send a messenger to the other saying "I am still here"
 - When no messengers arrive for longer than max minutes
 we can conclude that the other division has been defeated
- What about asynchronous pepperland?
 - We cannot distinguish wheather the other division has been defeated or the time for the messenger t cross the valley is just very long



Agreement in "failing pepperland"

- Suppose the messengers can be captured by enemies
- Can the two generals send messengers so that they both consistently decide to charge or surrender?
 - Reaching an agreement on one of the two possible decisions requires the successful arrival of at least one message
 - Consider scenario A in which the fewest delivered messages that will result in agreement to attack are delivered
 - Let scenario B be the same as A except that the last message delivered in A is lost in B, and any other messages that might be sent later are also lost
 - Suppose this last message is from General 1 to General 2
 - General 1 sees the same messages in both scenarios, so he definitely attacks
 - However, the minimality assumption of A implies that General 2 cannot also decide to attack in scenario B, so he must make a different decision
 - Hence General 1, not being sure its last message arrived, has wrongly decided to attack (both in scenarios A and B)
 - The problem is unsolvable



Impossibility of distributed consensus in practice

- Formally demonstrated by Fischer, Lynch, Patterson in 1985
- Does it really matter in real life? Yes!!!
 - Commit or abort a transaction in a distributed database
 - E.g., when you withdraw money at the ATM
 - Agree on values of replicated, distributed sensors
 - Agree on whether a system component is faulty
- How is it solved in practice?
 - Change the assumptions
 - E.g, make links reliable (enough)
 - Reduce the guarantees:
 - E.g., only probabilistic instead of deterministic