Today

- Naming
  - LDAP
- Physical clocks
- Clock synchronization algorithms

X.500 Directory Service

- OSI Standard
- Directory service: special kind of naming service where:
  - Clients can lookup entities based on attributes instead of full name
  - Real-world example: Yellow pages: look for a plumber

LDAP

- Lightweight Directory Access Protocol (LDAP)
  - X.500 too complex for many applications
  - LDAP: Simplified version of X.500
  - Widely used for Internet services
  - Application-level protocol, uses TCP
  - Lookups and updates can use strings instead of OSI encoding
  - Use master servers and replicas servers for performance improvements
  - Example LDAP implementations:
    - Active Directory (Windows 2000)
    - Novell Directory services
    - iPlanet directory services (Netscape)
    - OpenLDAP
    - Typical uses: user profiles, access privileges, network resources

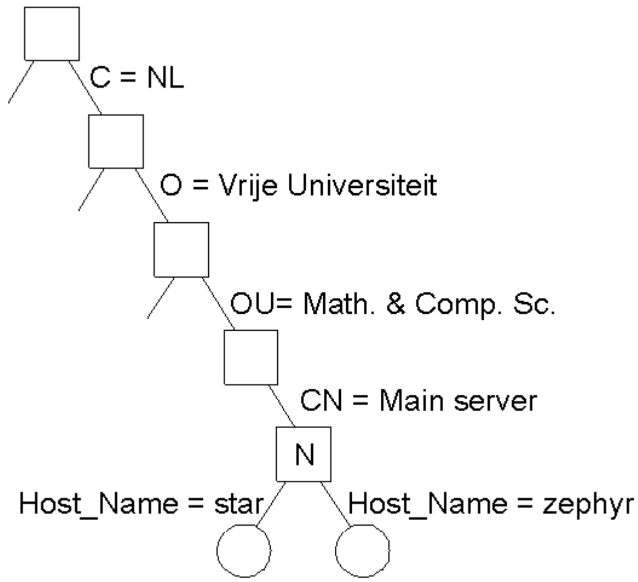
The LDAP Name Space

Attribute	Abbr.	Value
Country	C	NL
Locality	L	Amsterdam
Organization	L	Vrije Universiteit
OrganizationalUnit	OU	Math. & Comp. Sc.
CommonName	CN	Main server
Mail_Servers	--	130.37.24.6, 192.31.231,192.31.231.66
FTP_Server	--	130.37.21.11
WWW_Server	--	130.37.21.11

- A simple example of a LDAP directory entry using X.500 naming conventions.

The LDAP Name Space (2)

- Part of the directory information tree.

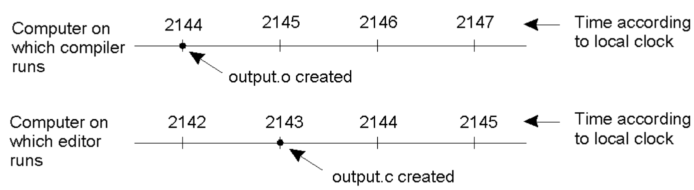


Canonical Problems in Distributed Systems

- Time ordering and clock synchronization
- Leader election
- Mutual exclusion
- Distributed transactions
- Deadlock detection

Clock Synchronization

- Time in unambiguous in centralized systems
  - System clock keeps time, all entities use this for time
- Distributed systems: each node has own system clock
  - Crystal-based clocks are less accurate (1 part in million)
  - *Problem:* An event that occurred after another may be assigned an earlier time

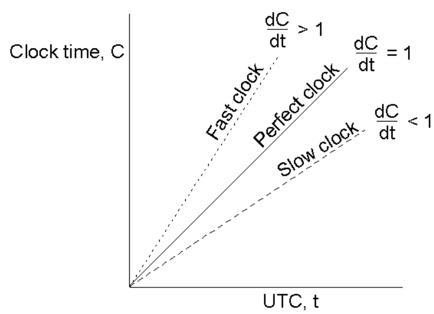


Physical Clocks: A Primer

- Accurate clocks are atomic oscillators (one part in 10^{13})
- Most clocks are less accurate (e.g., mechanical watches)
  - Computers use crystal-based blocks (one part in million)
  - Results in *clock drift*
- How do you tell time?
  - Use astronomical metrics (solar day)
- Coordinated universal time *(UTC)* – international standard based on atomic time
  - Add leap seconds to be consistent with astronomical time
  - UTC broadcast on radio (satellite and earth)
  - Receivers accurate to 0.1 – 10 ms
- Need to synchronize machines with a master or with one another

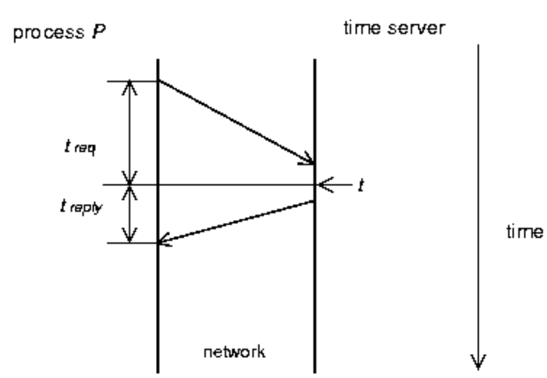
Clock Synchronization

- Each clock has a maximum drift rate ρ
  - $1-\rho <= dC/dt <= 1+\rho$
  - Two clocks may drift by $2\rho\ \Delta t$ in time Δt
  - To limit drift to δ => resynchronize every $\delta/2\rho$ seconds



Cristian's Algorithm

- Synchronize machines to a *time server* with a UTC receiver
- Machine P requests time from server every $\delta/2\rho$ seconds
  - Receives time t from server, P sets clock to $t+t_{reply}$ where t_{reply} is the time to send reply to P
  - Use $(t_{req}+t_{reply})/2$ as an estimate of t_{reply}
  - Improve accuracy by making a series of measurements



Berkeley Algorithm

- Used in systems without UTC receiver
  - Keep clocks synchronized with one another
  - One computer is *master*, other are *slaves*
  - Master periodically polls slaves for their times
    - Average times and return differences to slaves
    - Communication delays compensated as in Cristian's algo
  - Failure of master => election of a new master

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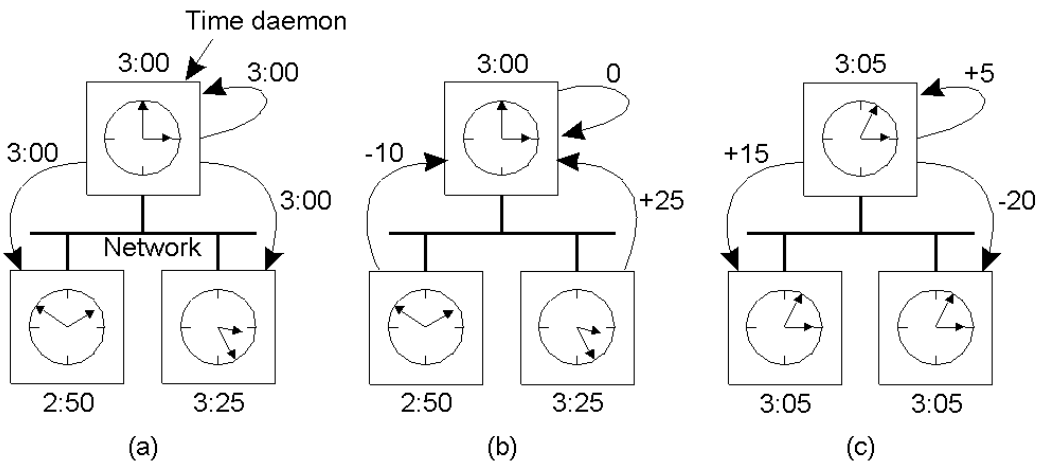
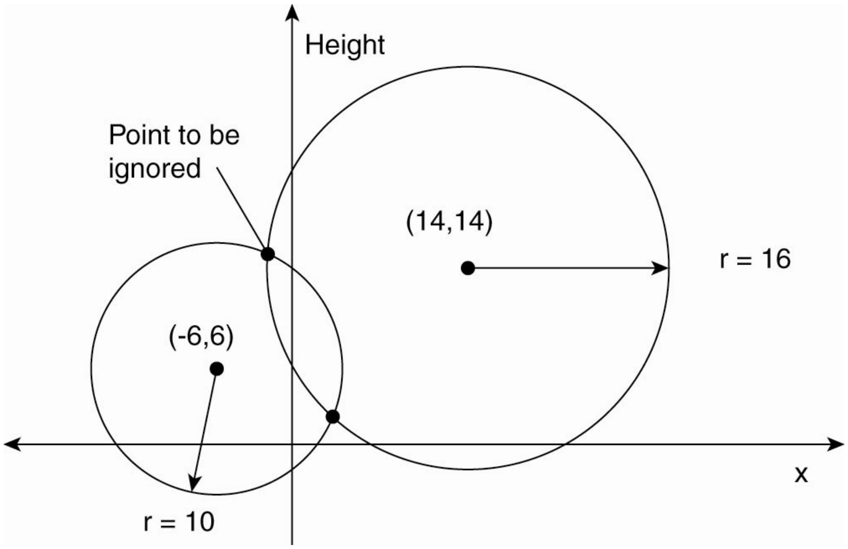


a) The time daemon asks all the other machines for their clock values
b) The machines answer
c) The time daemon tells everyone how to adjust their clock

Distributed Approaches

- Both approaches studied thus far are centralized
- Decentralized algorithms: use resync intervals
  - Broadcast time at the start of the interval
  - Collect all other broadcast that arrive in a period *S*
  - Use average value of all reported times
  - Can throw away few highest and lowest values
- Approaches in use today
  - *rdate*: synchronizes a machine with a specified machine
  - Network Time Protocol (NTP)
    - Uses advanced techniques for accuracies of 1-50 ms

Global Positioning System



- Computing a position in a two-dimensional space.

Global Positioning System

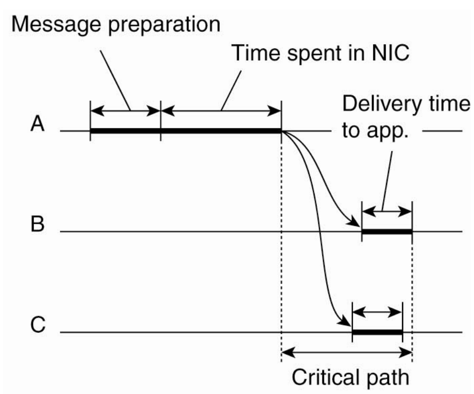
- Real world facts that complicate GPS

1. It takes a while before data on a satellite's position reaches the receiver.
2. The receiver's clock is generally not in synch with that of a satellite.

GPS Basics

- D_r – deviation of receiver from actual time
- Beacon with timestamp T_i received at T_{now}
  - Delay $D_i = (T_{now} - T_i) + D_r$
  - Distance $d_i = c\ (T_{now} - T_i)$
  - Also $d_i = \mathrm{sqrt}[\ (x_i - x_r)^2 + (y_i - y_r)^2 + (z_i - z_r)^2\ ]$
- Four unknowns, need 4 satellites.
-

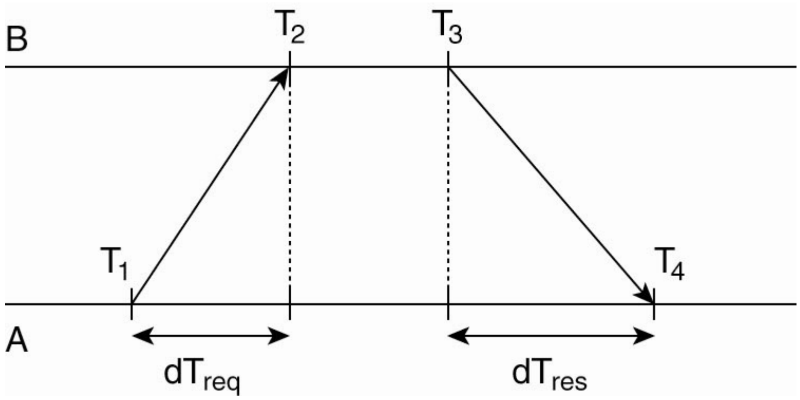
Clock Synchronization in Wireless Networks



(b)

- Reference broadcast sync (RBS): receivers synchronize with one another using RB server
  - Mutual offset = $T_{i,s} - T_{j,s}$ (can average over multiple readings)

Network Time Protocol



- Widely used standard - based on Cristian's algo
  - Uses eight pairs of delays from A to B and B to A.
- Hierarchical – uses notion of stratum
- Clock can not go backward

Logical Clocks

- For many problems, internal consistency of clocks is important
  - Absolute time is less important
  - Use *logical* clocks
- Key idea:
  - Clock synchronization need not be absolute
  - If two machines do not interact, no need to synchronize them
  - More importantly, processes need to agree on the *order* in which events occur rather than the *time* at which they occurred

Event Ordering

- *Problem:* define a total ordering of all events that occur in a system
- Events in a single processor machine are totally ordered
- In a distributed system:
  - No global clock, local clocks may be unsynchronized
  - Can not order events on different machines using local times
- Key idea [Lamport]
  - Processes exchange messages
  - Message must be sent before received
  - Send/receive used to order events (and synchronize clocks)

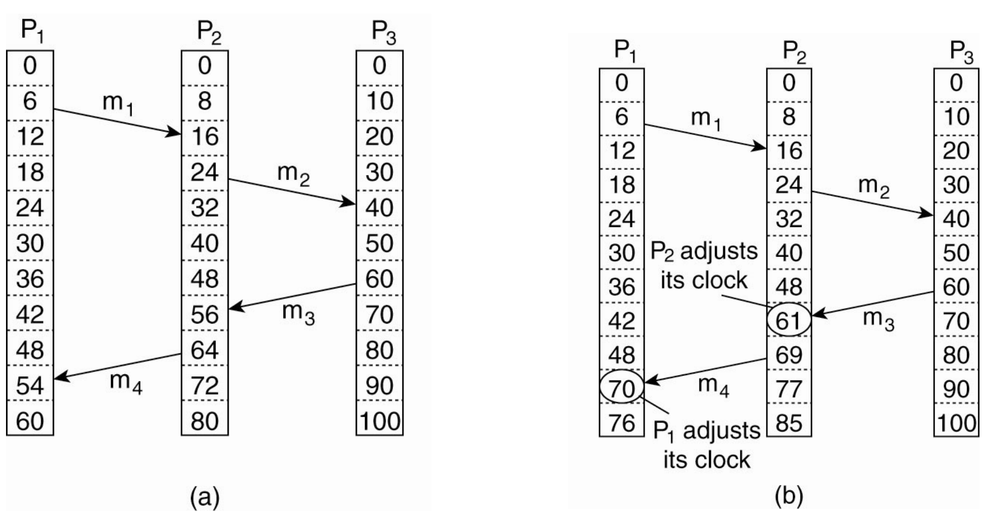
Happened Before Relation

- If *A* and *B* are events in the same process and *A* executed before *B*, then *A -> B*
- If A represents sending of a message and B is the receipt of this message, then A -> B
- Relation is transitive:
  - A -> B and B -> C => A -> C
- Relation is undefined across processes that do not exchange messages
  - Partial ordering on events

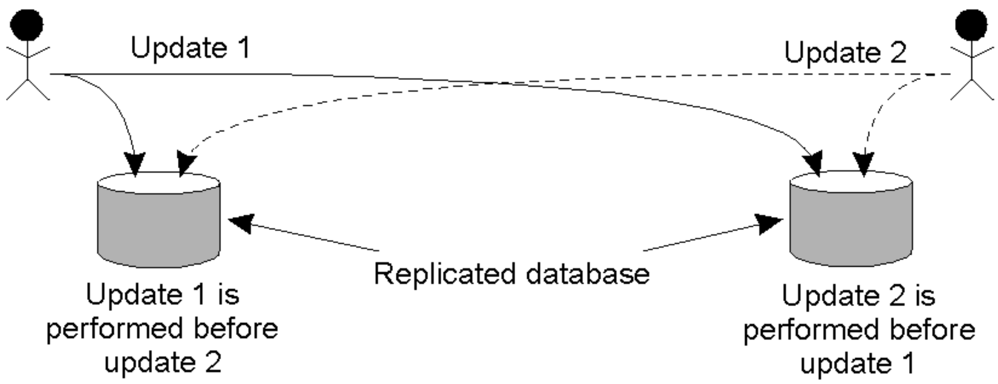
Event Ordering Using *HB*

- Goal: define the notion of time of an event such that
  - If A-> B then C(A) < C(B)
  - If A and B are concurrent, then C(A) <, = or > C(B)
- Solution:
  - Each processor maintains a logical clock LC_i
  - Whenever an event occurs locally at I, $LC_i = LC_i + 1$
  - When *i* sends message to *j*, piggyback Lc_i
  - When *j* receives message from *i*
    - If $LC_j < LC_i$ then $LC_j = LC_i + 1$ else do nothing
  - Claim: this algorithm meets the above goals

Lamport's Logical Clocks



Example: Totally-Ordered Multicasting



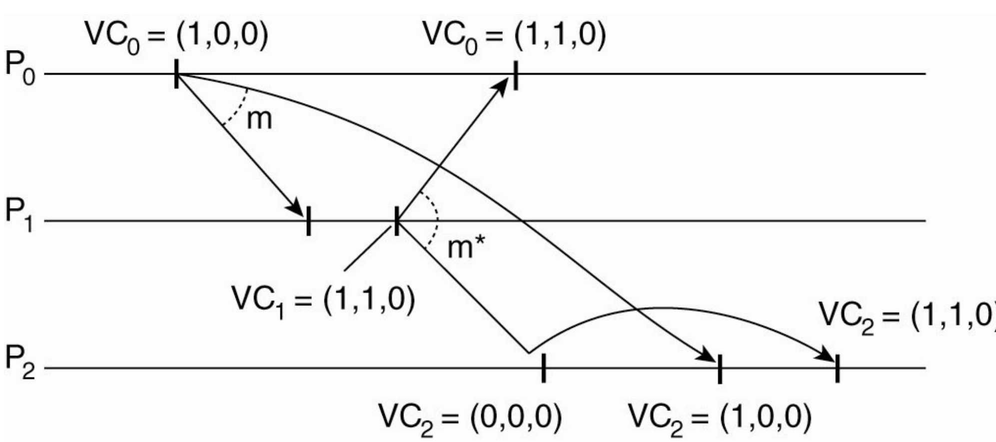
Causality

- Lamport's logical clocks
  - If *A* -> *B* then *C(A)* < *C(B)*
  - Reverse is not true!!
    - Nothing can be said about events by comparing time-stamps!
    - If *C(A)* < *C(B),* then ??
- Need to maintain *causality*
  - If a -> b then a is casually related to b
  - *Causal delivery*:If send(m) -> send(n) => deliver(m) -> deliver(n)
  - Capture causal relationships between groups of processes
  - Need a time-stamping mechanism such that:
    - If *T(A)* < *T(B)* then *A* should have causally preceded *B*

Vector Clocks

- Each process *i* maintains a vector V_i
  - $V_i[i]$: number of events that have occurred at i
  - $V_i[j]$: number of events I knows have occurred at process j
- Update vector clocks as follows
  - Local event: increment $V_i[I]$
  - Send a message :piggyback entire vector V
  - Receipt of a message: $V_j[k] = \max(V_j[k], V_i[k])$
    - Receiver is told about how many events the sender knows occurred at another process *k*
    - Also $V_j[i] = V_j[i]+1$
- *Exercise:* prove that if $V(A)<V(B)$, then *A* causally precedes *B* and the other way around.

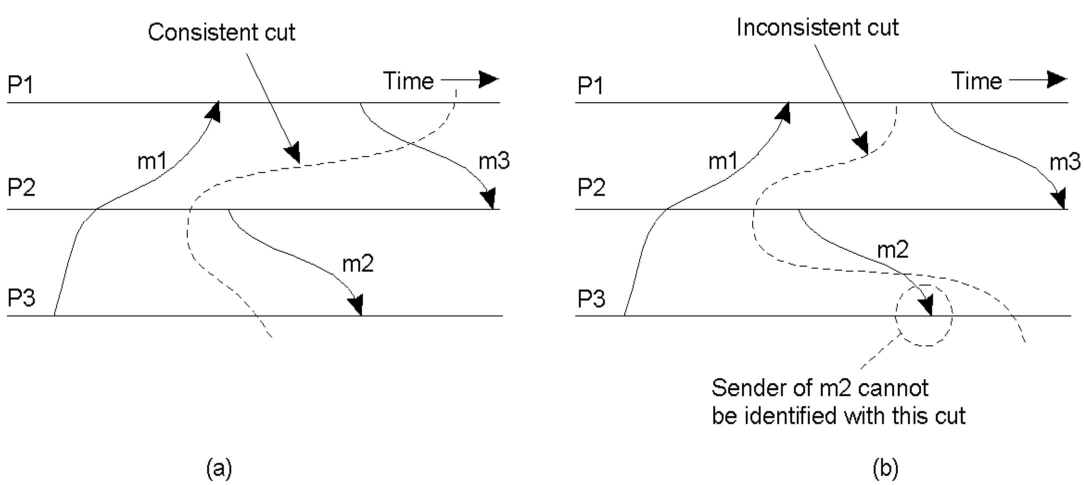
Enforcing Causal Communication

- 

Global State

- Global state of a distributed system
  - Local state of each process
  - Messages sent but not received (state of the queues)
- Many applications need to know the state of the system
  - Failure recovery, distributed deadlock detection
- Problem: how can you figure out the state of a distributed system?
  - Each process is independent
  - No global clock or synchronization
- Distributed snapshot: a consistent global state

Global State (1)



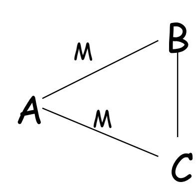
a) A consistent cut
b) An inconsistent cut

Distributed Snapshot Algorithm

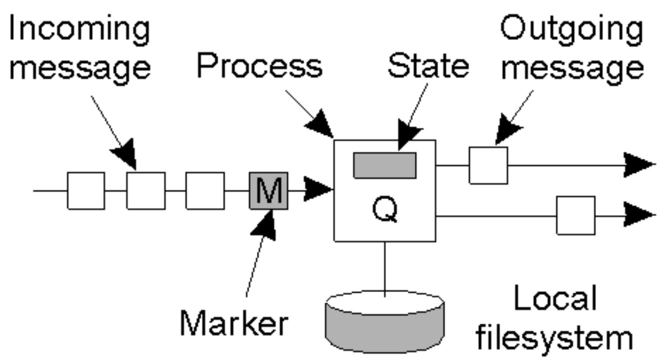
- Assume each process communicates with another process using unidirectional point-to-point channels (e.g, TCP connections)
- Any process can initiate the algorithm
  - Checkpoint local state
  - Send marker on every outgoing channel
- On receiving a marker
  - Checkpoint state if first marker and send marker on outgoing channels, save messages on all other channels until:
  - Subsequent marker on a channel: stop saving state for that channel

Distributed Snapshot

- A process finishes when
  - It receives a marker on each incoming channel and processes them all
  - State: local state plus state of all channels
  - Send state to initiator
- Any process can initiate snapshot
  - Multiple snapshots may be in progress
    - Each is separate, and each is distinguished by tagging the marker with the initiator ID (and sequence number)



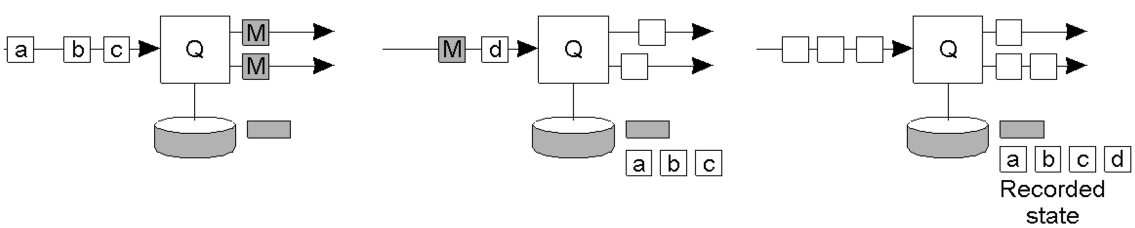
Snapshot Algorithm Example



(a)

a) Organization of a process and channels for a distributed snapshot

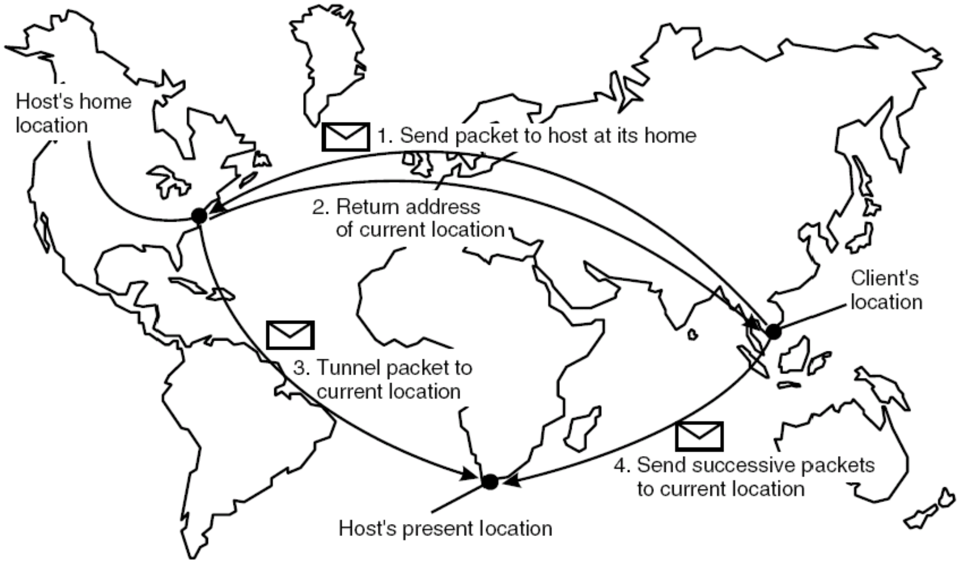
Snapshot Algorithm Example



(b) (c) (d)

b) Process Q receives a marker for the first time and records its local state
c) Q records all incoming message
d) *Q* receives a marker for its incoming channel and finishes recording the state of the incoming channel

Home-Based Approaches



The principle of Mobile IP.