Coexistence, Collaboration, and Coordination Paradigms in the Presence of Mobility

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Presentation Outline

- Presentation theme
- Prevailing trends
- Shifting foundations
  - Protocols
  - Algorithms
  - Formal models
- Paradigm shifts in middleware design
  - Coordination
  - Coexistence
  - Collaboration
- Conclusions
Presentation Theme

- Computing and communication in the presence of mobility demands a new way of thinking
  - Changes often invalidate fundamental assumptions
    - End of the cold war (1989)
  - We are on the cusp of a major technological and social realignment
  - Predicting the future is a risky proposition
    - Telephone (1876)
    - Internet (1969)
Prevailing Trends

... in which we learn that we are all in this together
Technology in Support of Mobility

- Miniaturization
- Wireless communication
- Localization technology
- Sensing devices
- Battery technology

- Code mobility

- Nomadic networks
- Ad-hoc networks
- Sensor networks
The Social Dimension

- A society on the go
- Growing expectations
  - Increasing reliance on information technology
  - Integration of computing and communication into the fabric of society
- Market acceptability and adoption emerging as powerful forces in technology development
  - Government policies and regulations unable to keep pace with technological advances
Application Development Opportunities

- Fire tracking and monitoring
- Ambulatory patient monitoring
- Container tracking
- Car to car interactions on highways
- Sensor assisted robot navigation

- Contents delivery on the phone
- Self managing assembly line
- Assisted airplane inspection and repairs
- Museum visit and city tours
- Disaster response
- Nature exploration
Shifting Foundations

… where we find out that there are things our teachers never told us
Protocol Design

... about sending messages to our friends and how to keep the highway clear
Multicast Revisited

- A multicast group is a set of nodes known to the world by a shared name
- A spanning tree that includes all group members is constructed and maintained
- Nodes may join and leave the group
- Data is delivered to all group members
Multicast Paradigms

Standard Multicast

Send data to: 138.5.6.7
Listen for: 138.5.6.7

Geocast

Send data to: Area (2, -1)
Listen for: 138.5.6.7
Listen for: 138.5.6.7
Mobicast: Spatiotemporal Multicast

- Just in time message delivery along a specified trajectory
  - Ambulance warning
  - Intrusion detection

clear the road!
Technical Challenges
A Mobicast Protocol Overview
Lessons Learned

- Mobility changes the questions we ask
  - mobile query—data prefetching and just in time delivery
  - location query and tracking
- Spatiotemporal constraints alter our perspective
- Geometric characterization is a useful tool
  - measures of sparseness
  - face aware routing
- Energy conservation impacts the solution space
  - sleep scheduling
  - message release order
  - workload shaping
Algorithms

... where we discover that keeping track of things is a messy business
Termination Detection

Diffusing computations are a special case
- one source of activity
- active nodes can wake up other nodes
- nodes may go idle at any time

Sample solutions
- counting
- weight throwing
- activation tree
Ad Hoc Network

- Migration of termination records
- Opportunistic routing
Wireless Cellular Network

- Tracking strategy
- Mobile-as-message model
Lessons Learned

- New concepts may be needed
  - weak vs strong termination
- Guarantees may need to be conditional
- Models may facilitate translation of knowledge
  - distributed algorithms recycled
- Communication may take place over disconnected routes
  - forwarding based on partial order
  - exploitation of motion profiles
Formal Models

... where the variable $x$ gets the value $v$ and sets an example for future things to come or go
UNITY

- The essence of concurrency
  - assignment statement
  - program as set of statements
  - nondeterministic selection
  - composition as set union

- Producer/Consumer

  $P :: \begin{align*}
  x & := x + 1 & \text{if } y = x \\
  \end{align*}$

  $Q :: \begin{align*}
  y & := y + 1 & \text{if } y \neq x \\
  \end{align*}$
Mobile UNITY

- The essence of mobility in open environments
  - location as a distinguished variable
  - motion reduced to value assignment
  - composition as set union plus interactions

- Producer/Consumer

\[
P :: \quad x := x+1
\]
\[
Q :: \quad y := y+1 \quad \text{if } b
\]

\[
Q.b := (P.x > Q.y) \land (P.\lambda = Q.\lambda) \text{ reacts to true}
\]
Lessons Learned

- Modeling open systems
  - power of the quantifier
  - coordination dimension
- Importance of conditional proofs
  - Mobile IP
- Expressive power shaped by real problems
  - complex high level interactions
  - mobile code
  - fine grained mobility
  - Context UNITY
Paradigm Shifts in Middleware Design

... in which we learn that one must have software to make software, a bit like making money
Coordination

… where a girl never finds out how to make the pie, and we discover that splitting a pie is in the eye of the beholder
Linda

- A global persistent tuple space
- Three primitive operations: `out(tuple); in(pattern); rd(pattern)`
- Decoupled computing
- Concurrency at minimal cost
Lime

- Agents can move among hosts and own tuple spaces
- Support for basic operations plus reactions
- Communication defines connectivity
- Hosts within communication range share data
Service Discovery

- The two hosts are too far away to communicate
- The two hosts establish contact
- Agent 2 can discover service A on Agent 1
Service Utilization

- Agent 2 uses service A offered by Agent 1
- Agent 2 continues to use service A which migrated to Agent 3
Security Enhancements

Diagram showing the layers of application, service provision, secure tuples, secure tuple spaces, security table, LIME, and remote interactions.
Lessons Learned

- Lime
  - specialization to mobility reduces development time
- Limone
  - minimal features can support many applications
- EgoSpaces
  - interest and context are highly individualized notions
- ServiceLime
  - adaptive, predictable, and continuous provisioning is of the essence
- CAST
  - spatial and temporal operations are needed in real applications
Coexistence

... in which we find out that needs are not always what they seem, wanting milk may be a veiled request for cream
Sensor Networks

- A permanent and pervasive network
- A shared computing resource
Agilla System Architecture

Node (1,1)
- Agents
- Neighbors
- Tuplespace
- Agilla Middleware
- TinyOS
- MICA2 Mote

Node (2,1)
- Agents
- Neighbors
- Tuplespace
- Agilla Middleware
- TinyOS
- MICA2 Mote

Arrow labeled "migrate" from Node (1,1) to Node (2,1)
Arrow labeled "remote access" from Node (1,1) to Node (2,1)
Spanning the Internet: Agimone

Network Architecture

System Components
Coping with Heterogeneity: Servilla
Lessons Learned

- Agent technology is feasible and effective for the development of sensor network applications
- High level programming is necessary
- A flexible virtual machine offers significant gains
- Deployment of multiple applications requires both admission control and resource allocation
- Heterogeneous resources demand increased reliance on dynamically bound services
Collaboration

… in which the internet is left behind and the work flows without
New Workflow Scenarios
CiAN Engine
Lessons Learned

- Workflows involving the physical world entail spatiotemporal considerations
- Task allocation in mobile settings is a complex undertaking
- Situation awareness is an important planning ingredient (e.g., motion profiles)
- Corporate knowledge enhances the ability to get the job done
- Open and emergent workflows are promising new directions for collaboration in the real world
Conclusions

- A new world order is emerging
  - virtual and physical
  - personal and social

- Mobility is integral to this fluid world which
  - demands malleable and flexible applications
  - supported by new conceptual frameworks
  - made possible by middleware
  - rooted in new technical foundations
Thank you …

… and here is my address

http://www.cs.wustl.edu/~roman/