The Internet of Things and Multiagent Systems: 
Decentralized Intelligence in Distributed Computing

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IoT Challenges

**Discovery**
- Physical objects
- Dealing with places
- Power source?
- Data services

**Usability**
- Identifying
- Manipulating
- Visualizing

**Governance**
- Autonomy
- Decentralization
- Sharing things

**Security**
- Integrity
- Privacy
- Owner’s
- Others’

**Distributed**
- Unreliable messaging
- Asynchrony
- Delay tolerance

- Provenance
- Trust

Dashed: Emphasis today
Internet of Oceans: Global Hybrid Profile Mooring Launch

Resource sharing, here for scientific collaboration
Internet of Oceans: Glider Being Launched

Intelligence at the end points
Vehicle Actuators

Remote configuration: Over the air modification of Tesla chassis elevation
Main Architectural Elements

Things
- Sensors
- Actuators

Middleware
- Discovery Selection
- Storage
- Monitoring
- Control

Applications
- User Interface
- Reasoner

Users

IoT emphasizes ownership and governance
Decentralization Calls for a Multiagent Architecture

Each agent represents an autonomous party; each Org represents an interaction context.
Vending Machine in Vienna

Conventional software engineering focuses on technical artifacts

AF[Brew]: On every path, coffee is eventually brewed
A[¬Brew U Coin]: On every path, no coffee is brewed prior to payment

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http://embsys.technikum-wien.at/projects/decs/verification/formalmethods.php
Vending Machine in Valencia

Users plus machine form a sociotechnical system

- Tall structure
- Hard to reach for short people
- Is that a bug or a feature?
Vending Machine Close Up: Cigarettes!
Regulation: Violations are Possible

Appropriate assumption when dealing with autonomous parties
IoT Federation Levels and What Flows Across

Current techniques: lower levels
IoT applications need upper levels

- Governance
- Services
- Ontology
- Connectivity
- Expectation
- Value
- Meaning
- Information
- Governance
- Services
- Ontology
- Connectivity

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Existing Approaches Ignore Expectations and Governance

Problems in ethics, trust, privacy, ...
Back to the Future

Current techniques: orchestration and a central mindset
IoT applications need decentralization and social protocols

Figure: Before IT: social but not computational

Figure: Current: centralized but computational

Figure: Envisioned: decentralized and computational
Sociotechnical Systems: Decentralized Intelligence

Requirements

Principal

... regulate

Principal

(Decentralization)
Social Tier

Technical Tier (Distribution)

data

read, write

Functional and Management Components

Stakeholders

specify

realized in

Expectations

Assumptions

Mechanisms

Metrics

identify

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Formalizing Expectations for Distributed Computing

Normative relationships or norms in Orgs: Declarative; composable; manipulable

Diagram:
- **Org**
  - Context
  - Antecedent
  - Consequent

- **Principal**
  - Practically Commit
  - Dialectically Commit

- **Norm**
  - Subject
  - Object

- **Antecedent**
  - Commit
  - Authorize
  - Prohibit
  - Sanction
  - Empower

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Simple Domain Model for Sociotechnical Systems

A vocabulary for governance

- **Action**
  - Organization
  - Participation
    - Eject
    - Admit
  - Registration
    - Contribute
    - Withdraw
  - Communication
    - Norm Operation
    - Create
    - Delegate
    - Assign
  - Resource
    - Owns
  - Norm State
    - Member
    - Registrant
    - Owns
  - Participation
    - Created
    - Violated
    - Satisfied
  - Resource
    - Capable
    - In
    - State
  - Property
    - Inform
    - Request
    - Query

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Summary: Decentralized Intelligence is Key for IoT

IoT applications need computational models of sociotechnical systems

- Programming models
  - How can we enacting social protocols?
  - How may we express expectations via norms?
  - How can we computationally support reasoning about social protocols?

- Interaction-oriented software engineering
  - What modeling constructs cohesively underpin multiple federation levels? Can a declarative treatment of causality yield such constructs?
  - How can we characterize autonomy and corresponding accountability?

- Enlightened governance
  - How can we evaluate the quality of norms?
  - How can we support social deliberation about norms?
  - What are high-level architectural abstractions that naturally incorporate governance?
  - How can we understand ethics in a tangible computational manner?
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http://www.csc.ncsu.edu/faculty/mpsingh/