Cooperative Systems of Physical Objects

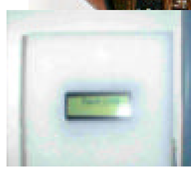
Hans Gellersen
Lancaster University

Physical Objects and Computation

- Perhaps a smart coffee cup?
- Mediacup (Karlsruhe, 1999)
- “Cooperation Added Value”

temperature watch

activity views



reactive doorplate

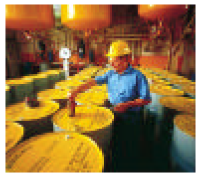
Smart Objects / Cooperation

- **Physical objects afford specific and limited interaction**
  - How they are handled, how they are configured
  - What they sense, what they affect is local and situated
- **Dynamic systems of smart objects**
  - Open-ended combinations
  - Potential for richer interactions, emerging use
- **Two Models**
  - Infrastructure-centric: the smartness in the infrastructure
  - Object-centric: all the smartness contained in the objects

Cooperative Systems of Objects

- decentralized: all computing embedded within the objects
- contextualized: preconceptions, affordances, situated use
- variable in configuration: resulting from physical use and movement of objects

Weight Table



Chemical Drums

Relative Positioning

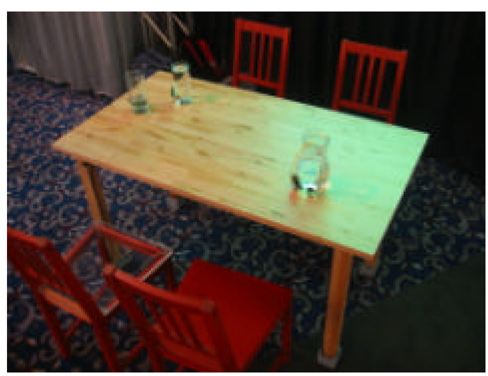
QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

Ad hoc physical interfaces

- How can objects collectively sense and reason about their environment
- How can mobile objects determine how they are arranged in space
- How can we build dynamic interfaces composed of cooperating devices

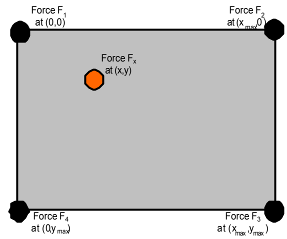
Weight Table

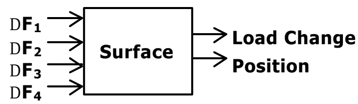
- Physical objects as a sensor network
- How can objects collectively sense more than the sum of individual observations ?
- How can we model activity in terms of objects and their state in the world ?



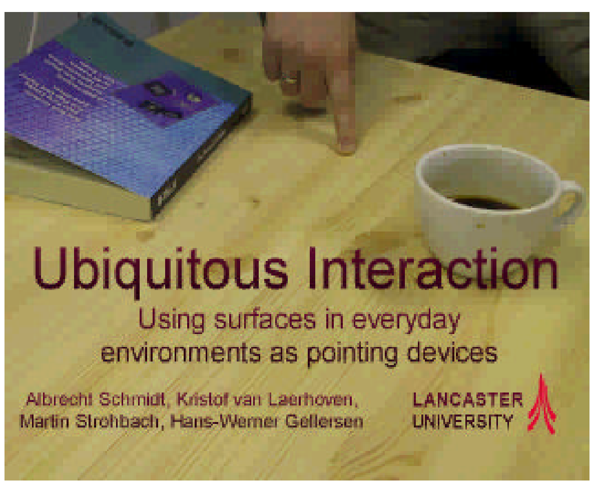
Sensing Activity on a Table Surface

- Instrument with load sensors to detect activity
- Measure load changes and where on the surface they occur
- Detect events: object placement and removal (load increase/decrease at x,y)
- Track movement on the surface: changes in load distribution





Weight Table Video



Sensing Activity on a Table Surface

How can we extend the system for identification of objects ?

- The table surface can detect that objects are placed and removed - but in abstraction of what they are
- All the table knows about an object is its weight

Identification requires additional information

- Background information: lookup table of weights – inherently limited and not scalable
- **Cooperation**: objects communicating their identity

Cooperation between Artefacts

Wireless communication

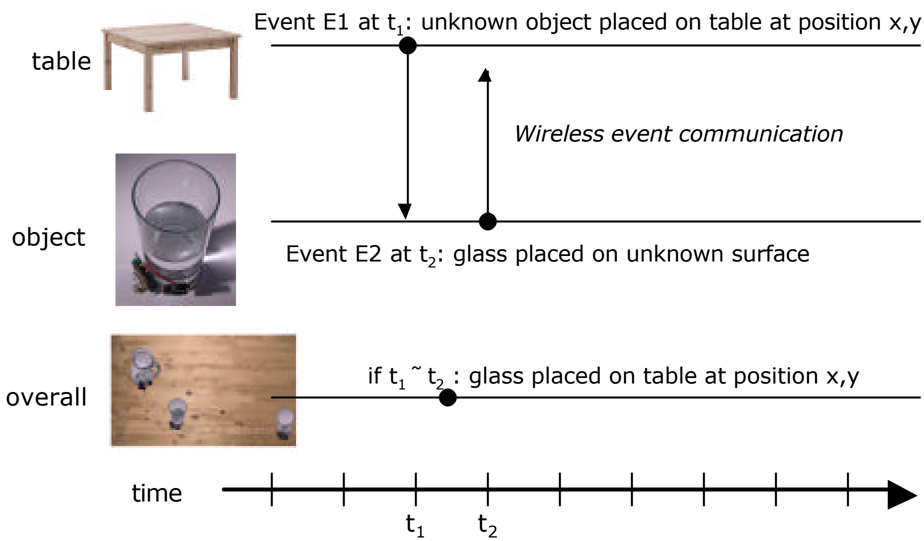
~~Identity~~

Weight

Table contains load sensors for object detection

Objects contain pressure sensors for placement detection

Event broadcast and correlation



Context Model

Table and other artefacts modelled with

- Built-in knowledge: identity, physical model
- Observable context
- Context that can be inferred collaboratively

Artefact / Entry Type	 Table	 Glass	 Jug
Identity	**identity(id)**	**Identity(id)**	**Identity(id)**
Physical Model	**dimension(x,y)** **origin(o)**	**n/a**	**tempModel(liquid)**
Observations	*unknownAt(x,y,w)*	*onSurface()*	*onSurface()* *temperature(temp)*
Inferred Entries	knownAt(A,x,y)	fillingState(f) position(refSys,x,y) weight(w)	fillingState(f) position(refSys,x,y) weight(w)

Activity Modelling in terms of Objects

- Traditional approach to activity modelling: scene analysis to abstract out 'what is going on'
- Constructing an activity model from distributed evidence
- Modelling activity in terms of changes in the world

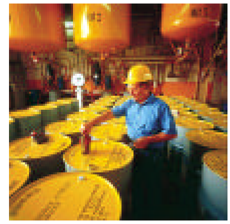
- Objects share evidence to each refine their own small view of the world
- Loosely coupled cooperation: objects in 'shouting range', implicit spatial scope

Chemical Drums

- Physical objects using sensors to observe their situation

- Cooperative reasoning: direct interaction to jointly assess a situation

Safety-Aware Chemical Drums

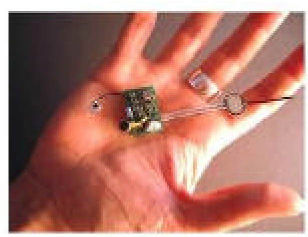


- "Storage Protocol Violations" are a major cause of accidents in the petrochemical industry
- Augment chemical drums to assess protocol compliance
  - Environmental conditions
    - Temperature, light
  - Handling and Usage
    - Shaking, dropping
  - Storage situations
    - Incompatible chemicals
    - Criticall mass
    - Unapproved area

Drum 'testbed'

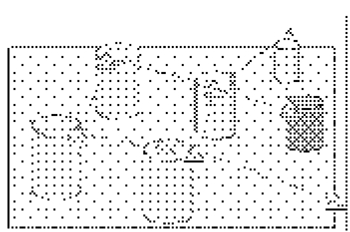
Technical Approach

- Instrumentation of drums
  - Sensing, ad hoc networking
- Embedding of domain knowledge (facts, rules)
  - Prolog-style
- Visual feedback



Smart-Its Computer

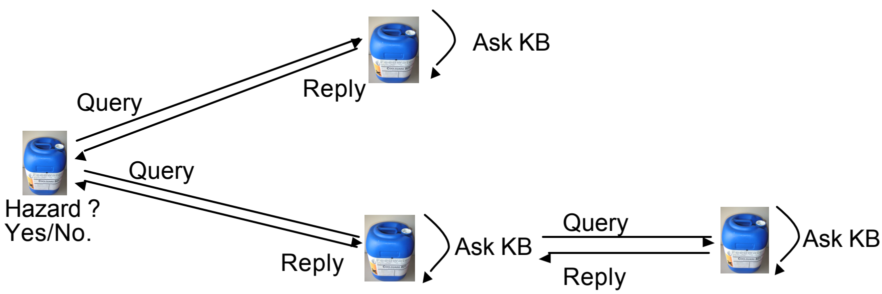
Safety- Aware Container



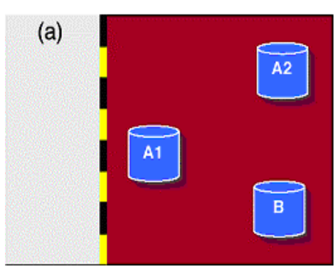
Ad hoc networked containers

Cooperative Reasoning

- Drums observe environmental conditions through their sensors
- Changes in the condition trigger rule evaluation
- Rule evaluation may require access to other drum's knowledge

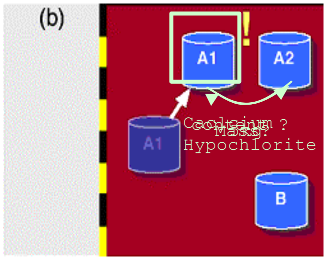


Test Scenario



Container a1	Container a2	Container b
location(me, in, 35)	**location(me, in, 55)**	**location(me, in, 49)**

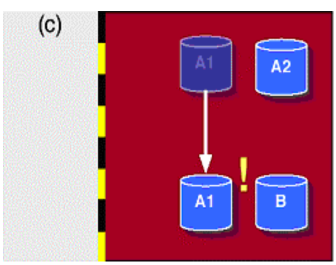
Critical Mass Hazard




```
hazard_critical_mass:-
 content(me, CH),
 cond_sum(M1,
   (proximity(me,C), content(C,CH),
       mass(C,M1)),S),
 mass(me, M2), sum(S, M2, SUM)
 critical_mass(CH, MASS),
 MASS < SUM.
```

Container a1	Container a2	Container b
proximity(me, a2)	**proximity(me, a1)**	-
content(me, Ca.2ClHO)	**content(me, Ca.2ClHO)**	
mass(me, 5kg)	**mass(me, 5kg)**	
location(me, in, 71)	**location(me, in, 91)**	**location(me, in, 85)**

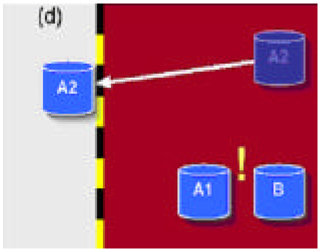
Incompatible Materials Hazard




```
hazard_incompatible:-
       content(me, CH1),
       proximity(me, C),
       content(C, CH2),
       reactive(CH1, CH2).
```

Container a1	Container a2	Container b
proximity(me, b)	**-**	**proximity(me, a1)**
location(me, in, 142)	**location(me, in, 154)**	**location(me, in, 147)**

Unapproved Area Warning

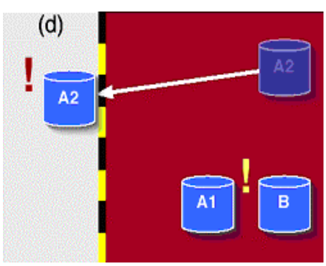



```
warning:-
        location(me, out, T1),
        content(me,CH),
        critical_time(CH,T2),
        T1<T2.
```

Container a1	Container a2	Container b
proximity(me, b)	**-**	**proximity(me, a1)**
location(me, in, 210)	**location(me,out,29)**	**location(me, in, 215)**

Unapproved Area Hazard

After one hour:




```
hazard_unapproved:-
        content(me, CH),
        critical_time(CH, T1),
        location(me, out, T2),
        T1 < T2.
```

Container a1	Container a2	Container b
proximity(me, b)	**-**	**proximity(me, a1)**
location(me,in,3810)	**location(me, out,3629)**	**location(me,in,3815)**

Chemical Drums Video

Cooperative Chemical Drums

- Detection and evaluation of complex situations through ad hoc networking of physical objects
  - feasible to embed knowledge, perception and reasoning in an efficient manner
  - no external infrastructure required: objects are not reliant on availability of infrastructure to assess their situation
- Knowledge in the application domain maps well to the rule-based approach implemented in the chemical drums
- More explicit treatment of spatial conditions
  - spatial scoping of the reasoning process
  - requires objects to understand their spatial arrangement

Relative Positioning

- Wireless sensor devices cooperating to determine their spatial arrangement
- Cooperative sensing to measure distances and relative orientation

Location Sensing

- Most location systems provide absolute location
- Often relative spatial information sufficient
  - Proximity: who is nearby …
  - Distance: where is the nearest …
  - Orientation: what's left of me …
- Conventional location systems
  - Fixed reference units and mobile 'locatables'
  - Separate roles for sender/receiver
- Relative Positioning
  - Network of peers
  - Bi-directional sensing

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

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“Relate” Ultrasonic Prototypes

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TIFF (LZW) decompressor
are needed to see this picture.

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- **Smart-Its Computer**
  - PIC, RFM
- **Ultrasonic sensor board**
  - Distance
  - Angle-of-arrival

- **Same architecture**
- **Packaged as USB dongle**
  - for use with mobile computers

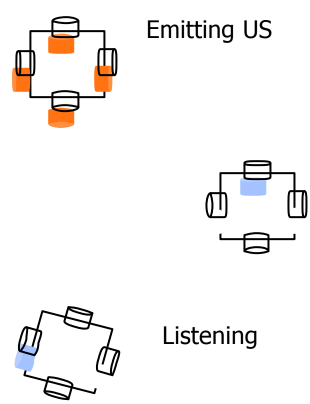
Cooperative Sensing

Networking

- Decentralized management of network state (no master)
- Medium access
  - to book the ultrasound channel to emit signals
  - to broadcast recent measurements over RF
  - round robin, or event-based

Sensing

- One node emits of ultrasound pulses in all directions
- All other nodes listen on ‘one side’ (ie. one transducer)
- Repeat until listeners have taken measurements ‘on all sides’



Cooperative Sensing

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TIFF (LZW) decompressor
are needed to see this picture.

- Time-slotted protocol, 13ms slots
- Broadcast own view of network state (RF)
- Broadcast measurements recently taken (RF)
- Transmit ranging pulses (US)
- Send measurements to USB host (USB)

Experimental Setup and Performance

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- **90th percentile accuracy**
  - 5-9 cm distance (good vs poor line of sight)
  - 20-30^0 in angle-of-arrival
  - Transmission cycle ~100ms
    5 devices -> updates every half second

Relative Positioning Video

Relative Positioning

- The RELATE system implementation
  - Highly accurate relative positions and reasonable orientation estimates
  - Limited range (direct sensing range ~3m), designed for 2D (with decreasing performance in non-planar arrangements)
- Close cooperation of dedicated sensor objects to determine spatial arrangement
- A general method to provide spatial information in peer-to-peer systems

Ad hoc Physical Interfaces

- Physical interfaces that can be composed and adapted on the fly
- Autonomous interactive objects as building blocks

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Ad hoc Physical Interfaces

Fabric Interface Concept

- Dynamic arrangement of interface objects on an interface substrate
- The substrate defines the physical interface area, the inserted devices the available functions

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Afforded interactions

- Attachment of objects
- Manipulation
- Detachment

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Technical Approach

Architecture

- Autonomous interface objects
  - Tiny computer with dedicated interactive capability
  - Programmable self-description
- Substrate to connect objects physically and digitally
  - Layered conductive material providing a ‘flat’ power and data bus
- Protocols for interface management
  - Maintaining interface configuration
  - Mediating between application and interface objects

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TIFF (LZW) decompressor
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TIFF (LZW) decompressor
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DrumFabric Video

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TIFF (LZW) decompressor
are needed to see this picture.

Fabric + Reason Video

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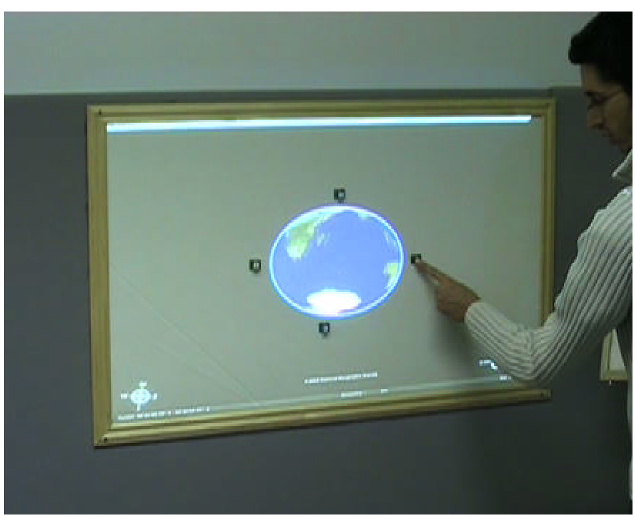
are needed to see this picture.

Google Earth Video



Fabric Discussion

- The FABRIC system implementation
  - Hardware/software toolkit for construction of ad hoc physical interfaces (flexible substrate, range of devices)
  - Limited power and data rate, no positioning of objects
- Centralized coordination of interface objects
- Interface design as ad hoc network of interactive elements provides for very flexible use
  - Ad hoc composition, re-arrangement, adaptation

NEARLY THE END NOW …

Cooperative Systems of Physical Objects

- Physical objects are becoming integrated with computing systems
- “extreme” systems: completely decentralized, with no infrastructure support for the physical objects
- Objects cooperating to model activity/situations “bottom-up”
- Cooperative sensing to determine spatial arrangement
- Coordination of ad hoc configured interface elements to provide for a new form of very dynamic physical interface

READY FOR QUESTIONS …

Acknowledgements

- colleagues and students at Lancaster
- project partners in EQUATOR, RELATE and COBIS
- Funders: EPSRC, EC.