Episode 15: Context Awareness

Hannes Frey and Peter Sturm
University of Trier
based on slides by Christian Becker, University of Stuttgart

Definition of Context

- Context (Merriam Webster)
  - contexere: to weave together
  - The parts of a discourse that surrounds a word or passage and can throw light on its meaning
  - The interrelated conditions in which something exists or occurs
- Related to Environment

Context by Schilit, Adams, Want

- Three important aspects of context are
  - Where you are,
  - Who you are with, and
  - What resources are nearby
- Context-aware systems adapt according to the location of use, the collection of nearby people, hosts, and accessible devices, as well as the changes to such things over time. A system with these capabilities can examine the computing environment and react to changes in the environment.

- Schilit, Adams, Want:Context-Aware Computing Applications

Context by Dey

- Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.
- A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user‘s task.

- Dey: Understanding and Using Context

Context by Chen, Kotz

- Context is the set of environmental states and settings that either determine an application's behavior or in which an application event occurs and is interesting to the user.
- Active context awareness: an application automatically adapts to discovered context, by changing the application's behaviour.
- Passive context awareness: an application presents the new or updated context to an interested user or makes the context persistent for the user to retrieve later.

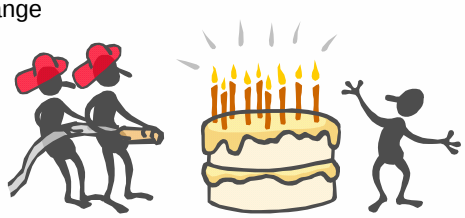
- Chen, Kotz: A Survey of Context-Aware Mobile Computing Research

Common Examples

- Position
  - Required for geographic routing
  - Position-specific information and/or advertisments
    - Traffic congestion, accidents, and other information
    - Where is the next restaurant?
    - Navigation, …
- My neighborhood
  - Again for routing issues

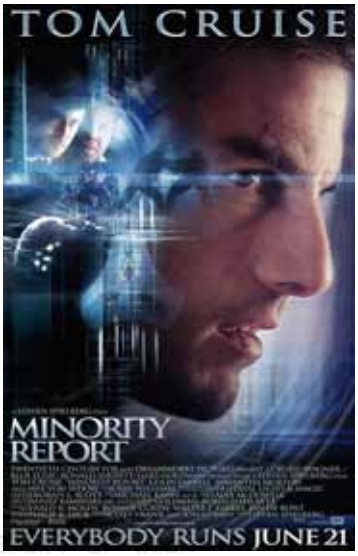
Reasons to be Context Aware

- Functional
  - Context-specific services and applications
    - Position of persons and things
    - Selection and Filtering of information
- Non-Functional
  - Overcome limitations
    - Restricted user interfaces
    - Limited electrical power
    - Limited communication range
    - Limited mobility



Context Scenarios

- Telecommunications
  - Depending on the number of people in a room, a mobile phone decides to ring normally or to vibrate only
  - Roaming the device (from wired phone to mobile)
- Presentations
- Human-Computer Interaction
  - Using the best input/output devices within reach (e.g. Minority Report)



Context Types

- Computing Context
  - Network connection
  - Communication costs
  - Nearby resources (displays, printers, …)
- User Context
  - User's profile
  - Location
  - People nearby
  - Current activity
- Physical Context
  - Lighting
  - Noise level
  - Traffic conditions

Context-Aware Applications - Categories

- Active context
  - Presentation of information and services to a user
  - Selection of services or information for a user
  - Automatic execution of a service for a user
- Passive context
  - Tagging of context to information for later retrieval

Examples - Presentation

- Navigation
  - Find a route from A to B
  - Dynamic information (traffic jams, crowds, detours, …)
- Location-based services
  - Present interesting targets (restaurant, printer, friends, …)
  - May lead to a navigational task
- Multi-modal interfaces
  - Changing HCI depending on
    - Velocity
    - Device properties
    - User preferences (visually impaired people)

Examples - Selection

- Select the next printer
- Booking and reservation systems
  - Account for user preferences (no smoking, etc.)
- Navigation systems
  - Context-dependent restrictions
    - avoid stairs for people in wheelchairs
  - User preferences
    - Elevators instead of stairs
  - Dynamic information
    - Traffic jams, detours, …

Example - Execution

- Ambient intelligence
  - Phyiscal environments reacts according to user profiles
  - Lighting, heating, …
  - Background music, …
- Teleporting
  - User interfaces follow users
- Spatial events
  - Actions triggered by events in the phyiscal world
    - Notify if within reach
    - Act on meeting
    - Entering or leaving buildings
    - …

Examples - Tagging

- Audio and video recording
  - Add time information (state of the art)
  - Add position information
    - Currently discussed extension to digital photography ☺
- Tagging with pictures
  - “The car is locked, Peter” says my PDA
- Reminder
  - Post-it notes
  - Active badges
  - …

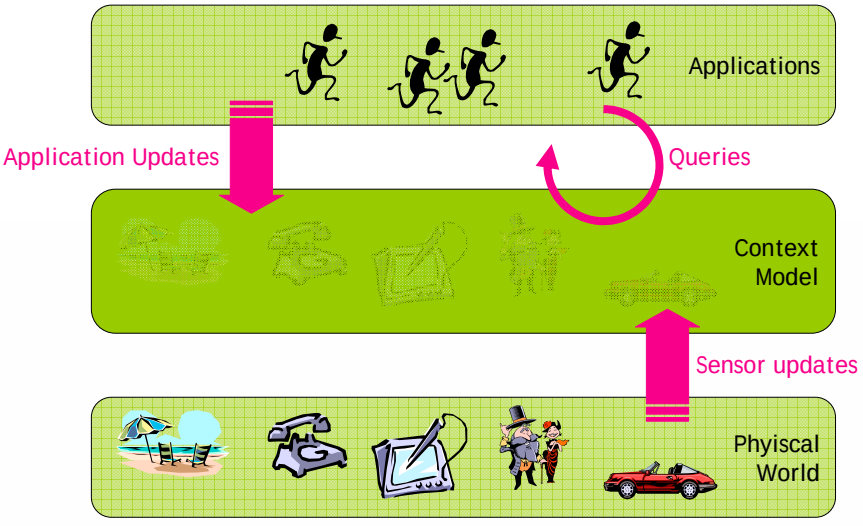
Image Tagging

Why models?

- A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task (Dey)

- How to retrieve context?
- How to represent context?
- How to store and manage context?
- How to access context from applications?
- How to share context among applications?

A Generic Context Model



Sources of Context Information

- Sensors
- Applications
- Static environmental information
- Preferences

Sensors

- Positioning systems
- Physical sensors
  - Temperature
  - Acceleration
  - Light
  - …
- Sensor Fusion
  - Light, more than n people, noise ⇒ Room occupied
  - Dimmed Light, more than n people, 1 speaking ⇒ Presentation
  - ...

Applications

- State of services
  - User roaming possible
- specific information
  - Context tags

Static Environmental Information

- Reference points
  - Symbolic names
    - /World/Germany/Trier/…
  - Geometric
    - Trier:
      - Latitude 49 45N
      - Longitude 006 40E
- Topological information
  - Floor plans
  - Road network
  - City maps

Preferences

- User
  - Schedule
  - Affection
  - Limitations
    - e.g. Visually impaired person ⇒ Audio output
- Applications
  - Requirements on services, devices

Context Classification by Source

- Static
  - Context is created and never (or rarely) changed
    - e.g. Trier doesn't change its geographic position very often
- Dynamic
  - Information is updated frequently
    - Periodically
    - On Demand
- Sensed
  - Information is obtained by sensors
  - Reflection of certain physical world properties
- Application provided

Context Representation

- Sensors
  - Named value pairs, e.g. (sensor1399,42)
  - SensorML (OpenGIS Consortium)
    - XML schema
- Applications
  - Various techniques used
- Static environmental information
  - Implicit
  - Explicit
    - Road networks (GDF77, ATKIS, …)
    - …
- Preferences
  - Various techniques used
- Trend towards XML-based representation

Example SensorML

```
<?xml version="1.0" encoding="UTF-8"?>
<!-- edited with XML Spy v4.3 U (http://www.xmlspy.com) by Michael E Botts (University of Alabama in Huntsville) -->
<Sensor xmlns="http://www.opengis.net/sensorML" xmlns:iso19115="http://www.isotc211.org/iso19115/" xmlns:gml="http://www.opengis.net/gml"
xmlns:ows="http://www.opengis.net/ows" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns:xlink="http://www.w3.org/1999/xlink"
xsi:schemaLocation="http://www.opengis.net/sensorML ../sensor.xsd http://www.opengis.net/sensorML ../responseModels/generalResponse.xsd" id="YSI_WS_0001">
    <identifiedAs>
        <shortName>Wind Speed Sensor 0001</shortName>
        <longName>YSI Wind Speed Sensor at Station 0001</longName>
        <type>http://www.opengis.net/sensor#anerometer</type>
    </identifiedAs>
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                    <gml:TInstant>
                        <gml:tPosition>2002-02-03T12:09:00.00</gml:tPosition>
                    </gml:TInstant>
                </gml:begin>
                <gml:end>
                    <gml:TInstant>
                        <gml:tPosition indeterminatePosition="after"/>
                    </gml:TInstant>
                </gml:end>
            </gml:TPeriod>
        </validTime>
    </documentConstrainedBy>
    <measures>
        <Measurand>
            <name>Wind Speed</name>
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            <characterizedBy>
                <dynamicRange axis="http://www.opengis.net/observables#windSpeed">
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                    <high uom="http://www.opengis.net/units#mph">134.0</high>
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            <basedOn>
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                                    <gml:pos srsName="http://www.opengis.net/crs#epsg4326" dimension="2">35.4 -85.8</gml:pos>
                                </gml:Point>
                            </location>
                        </ObjectState>
                    </locatedUsing>
                </Sample>
            </basedOn>
        </Measurand>
    </measures>
</Sensor>
```
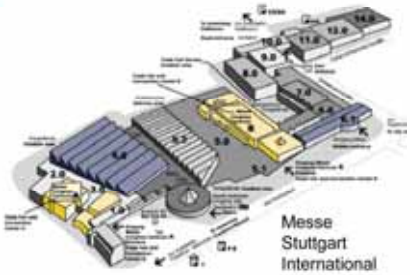

Accessing Context

- Example: Visiting a fair

John wants to visit the fair in Stuttgart

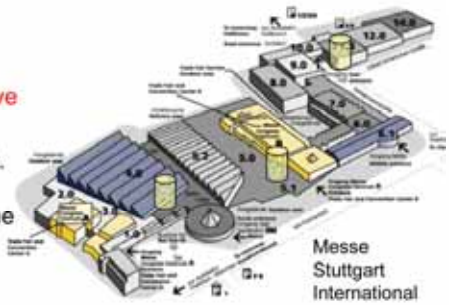
- Hotel reservation: 30 min distance to fair; and quiet surroundings.
- After arrival at the airport John wants to be navigated to the public transportation.
- The system recommends the S2 train with vacancies in the first two wagons.
- On the train a switch of trains to U7 Direction „Killesberg" is indicated.
- At the fair the system prompts for a confirmation to buy an electronic ticket.
- Approaching the entrance, the door automatically opens.



Messe Stuttgart International

Visiting a fair (contd.)

- A virtual Information Tower automatically displays information about its vicinity on John's system.
- John leaves a virtual note for colleagues at a booth indicating that he already made contact.
- John made a tentative appointment with Carol in Hall 8 between 10 and 11. The system reserves a meeting room and navigates both to the room when both have entered Hall 8.
- Back home, John prepares a travel report. He queries the system which exhibits he visited in Hall 8 in the morning and who the contact person was.



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Querying a Context Model

- Primary Context
  - Identity
  - Location
  - Time
- Who
- Where
  - Where is an object (position query)
  - Which is the next object (next neighbor query)
  - Which objects are there (range query)
- When
  - Current (point in time)
  - Past history
  - Future: prognosis (will there be traffic jam on my journey)

Context Model Organization

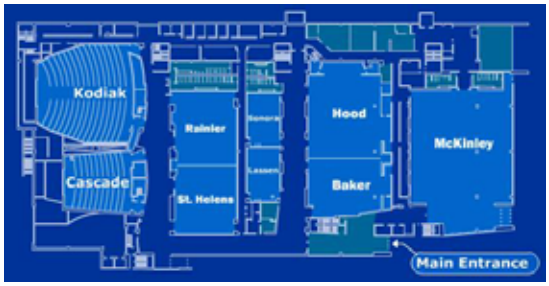
- Spatio-temporal organization required
  - Required for queries on primary context
    - Location
    - Time
- Spatial relationships can vary
  - Geometric reference systems
  - Symbolic coordinates
    - Cell ids (mobile phones, WLAN access points)
    - Infrared beacons
    - Seat number, room number, etc.

Position, Nearest Neighbor, Range

- Position queries
  - Position(id) ⇒ Location
  - Map of ids and locations
  - Variation of a directory service
- Nearest neighbor queries
  - Notion of “near” required
  - Geometric predefined metric
  - Symbolic: additional information required ⇒ Location model
- Range queries
  - Notion of “includes” required
  - Geometric: spatial inclusion defined by metric
  - Symbolic: additional information required ⇒ Location model

Location Models

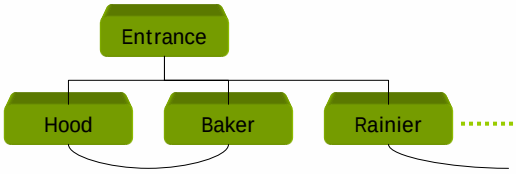
- Geometric locations
  - 2D and 3D
  - GPS
  - ActiveBat
- Symbolic locations
  - Building/Floor/Room
  - ActiveBadge
- Hybrid systems
  - Combining techniques for indoor and outdoor



- see episode 6 (Location)

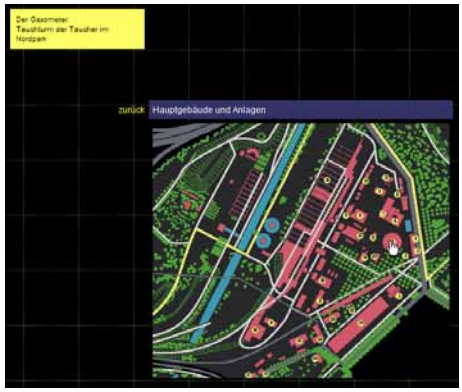
Symbolic Location Models

- Locations modeled as nodes
- Edges represent connections
- Edges and nodes weighted to indicate size resp. distance
- Reflecting spatial inclusion by hierarchies



Hybrid Location Models

- Coexistence of symbolic and geometric coordinates
- Annotate symbolic map with geometric coordinates
- Annotate geometric map with symbolic coordinates

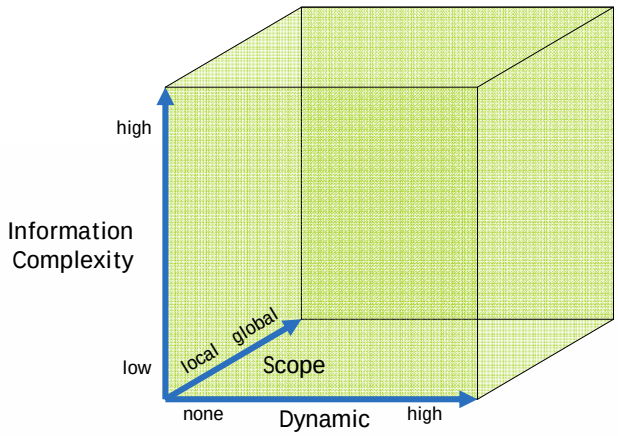


Complexity of Context Information

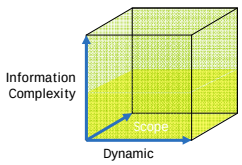
- Level of detail
  - 2D, 2.5D, and 3D models
  - Topological information
  - Geometric references
- Integration of dynamic data
- Multiple sources for context data
  - different representation of same information (consistency)
- Scope
  - Local context model for building, floor, car, etc.
  - Up to global context models

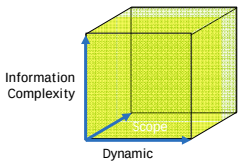
Classification of Context Models

- Complexity, Scope, and Dynamics



Common Settings





- Simple context model
- Telematic Services
  - Passo
  - Tegaron

- Increased complexity
- Examples
  - Guide
  - Cyberguide
  - Stick-e-Notes

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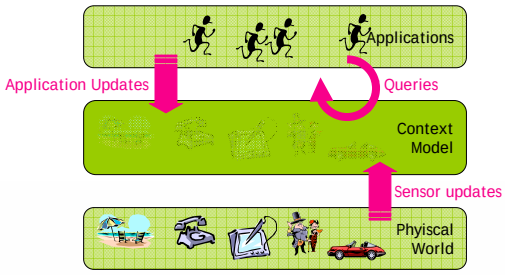
Context Management

Context Management

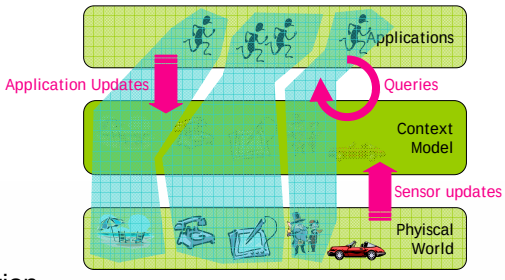
- Tasks
  - Context representation
  - Model changes and evolution
  - Context queries and updates
- Classification
  - Application specific or with support for sharing
  - Scope, complexity, and dynamics
  - Interoperability (semantics)
  - Interaction mechanism (service model)

Shared Context

- Standardized description of context required
- Extensibility
- Interoperability
- "Persistent" storage of context for re-use
- Dedicated context service needed



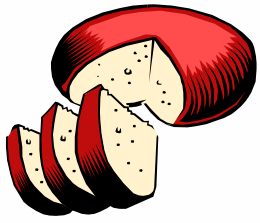
Application specific Context



- Legacy solution
  - Representation defined by application
  - Re-use of gathered context at least complicated
  - Context model may be defined as part of application
- Early implementations of context aware apps

Share all or share parts?

- Not all context is suitable for sharing
- Which context should be shared?
  - Information of overall importance
  - Independent context
  - Probably context not generated by applications (sensor data, …)
- Application specific context?
  - Internal state, …
- Context models should cover both



Issues in Shared Context Models

- Scalability
  - Number of context sources
  - Number of applications/clients
  - Influence of scope and dynamics
- Interoperability and extensibility
  - Common representation (probably XML)
  - Query language (XQuery or something specific?)
- Application scenarios
  - Sharing complicated in multihop ad-hoc networks
  - Easier in traditional client/server landscape with mobile clients
    - Database systems

Scalability

- Location Management
  - Billions of mobile objects
  - High accuracy ⇒ high update frequency
- Object complexity
  - Billions of stationary context information
  - Possibly high detailed models (3D data, …)
  - Changes in physical word may lead to complex changes in context model
- Combined queries
- There will be no single context management system for the whole world ☺
  - Open, federated management required (Needed?)

Interoperability and Extensibility

- Interoperability
  - Common representation
  - Common Semantics
    - Problems
      - Taxi = Cab?
      - Drucker = Printer?
    - UDDI (Universal Description, Discovery, and Integration)
  - Standardized query language
- Extensibility
  - How to add and manage new context?
  - How to augment with semantic

Service Models

- Pull Approaches
  - Applications query the context system
  - Identity, Location, Time
    - Position, nearest neighbor, range
- Push Approaches
  - Applications register callback function with context system
  - Notification about changes
  - Simple or complex trigger conditions
    - Predicates (e.g. for sensor fusion)
- Both approaches are required

State of the Art

- There is no common view on context and its requirements yet
  - Legacy models instead of context sharing
  - Many contradictory requirements
  - Many approaches
- Current focus on specialized context models
  - Domain specific
  - Fixed set of context information
  - Local scope or global with fairly restricted context information
- A single context model of the world?
  - Some dream of it (Ontologies, Semantic Web, etc.)

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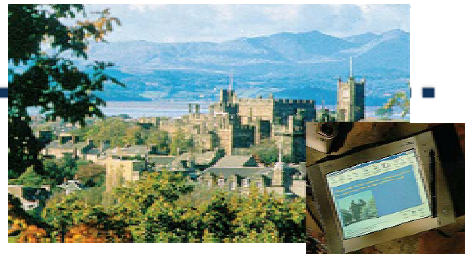
Examples

Infostations

- Used in many modern museums
- infostation near an exhibit provides detailed information
  - Visitors approach infostation
  - Offer of information
  - User preferences
    - Language
    - Level of detail
    - …

Oceanis, Wilhelmshaven

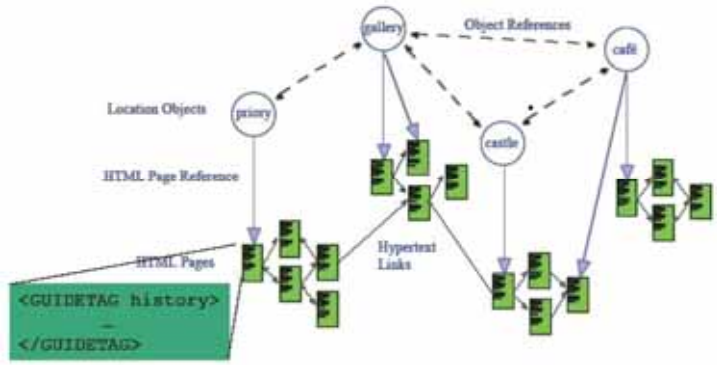
Guide



- N. Davies, K. Cheverst, K. Mitchell
  Universty of Lancaster
- Deployed system to support tourist information at Lancaster
- Context
  - Information relevant for tourists
    - Tour planning, historical information, interesting detours, …

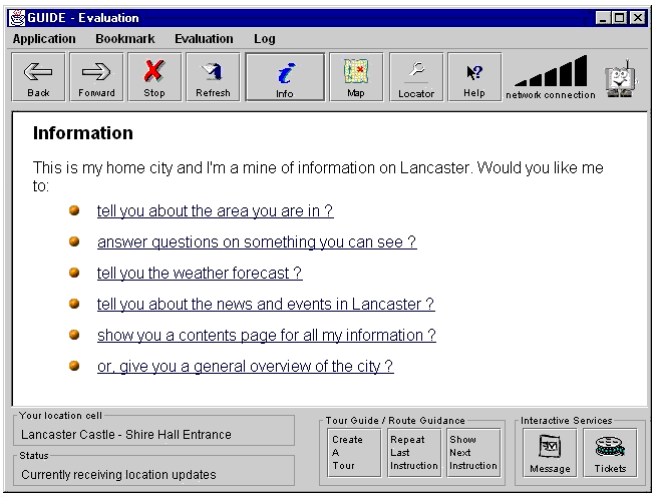
Guide Context Model

- 15.3 MB of content
- 409 navigation points
- Information linked to location
- Location indicated via WaveLAN cells

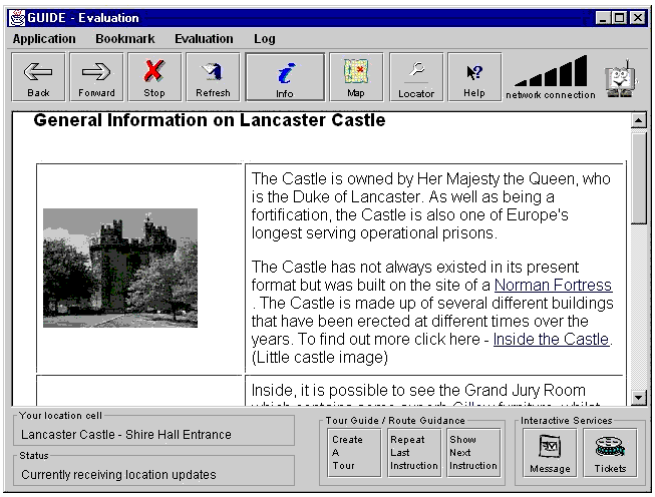


Guide Screenshots (1)

Guide Screenshots (2)

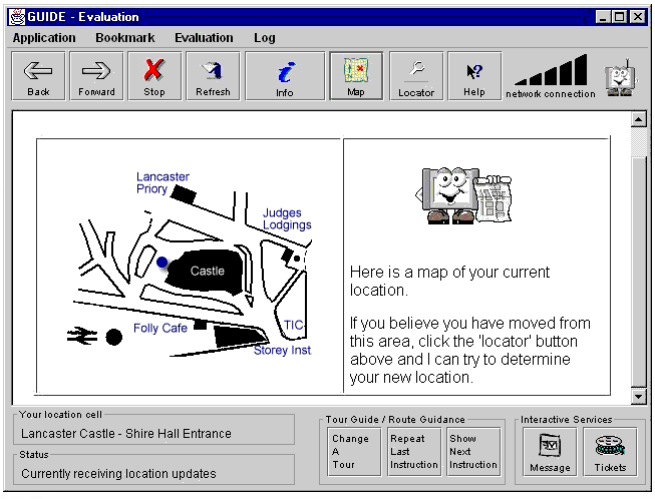


Guide Screenshots (3)



Guide Screenshots (4)

Guide Screenshots (5)



Guide II

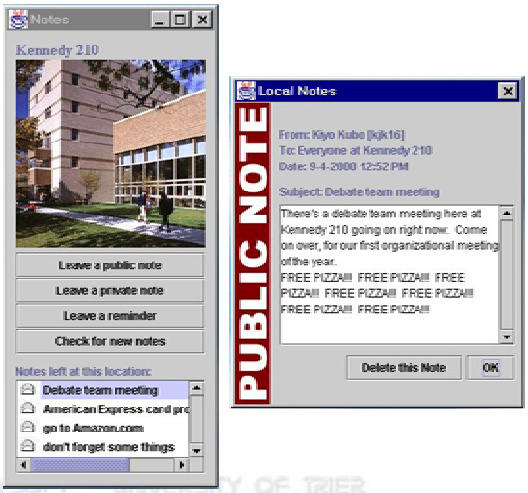
- Reflect recent advances in networking technologies
- Interfacing with existing service providers
  - Local traders, café owners, taxi services, etc.
- New services
  - Educational tours through time
  - “Famous” tours of the city
  - Supporting advanced reading by tourists
  - Keeping in touch with loved ones
  - Virtual city games
  - Use of streaming media

Stick-e Notes (1995-)

- P. Brown, D. Morse, J. Pascoe, N. Ryan
  University of Kent
- Framework for context-aware applications and services based on a Post-It note metaphor
  - Attaching objects to a particular context
- Project concentrates
  - user interface issues
  - Applications for animal behavior studies
  - Location issues via GPS

Graffiti

- J. Burrell, P. Treadwell, G.K. Gay
  Cornell University
- Attaching text notes to locations
- Reading notes posted at current location



MITthril – Context Aware Cell Phones

- MIT Media Lab (Richard W. DeVaul, Steve Dunn)

Cell phones represent the best and worst of modern wireless technology. Cell phones are one of the most popular tools of the early twenty-first century, facilitating business, recreation, and vital emergency communication. As the technology has become more popular, the social and safety problems associated with its wide-spread use have become more apparent. Cell phones are valuable tools, but they are also a significant distraction; The consequences of this distraction can range from socially inappropriate to life-threatening depending on the circumstances.

The Problem

We have all experienced the down-side of cell phone use; Cell phones ring in movie theaters, meetings, restaurants, and while we are in important face-to-face conversations. In some parts of the world restaurant and theater owners have gone so far as to employ cell phone jamming technology to limit the disruption caused by inappropriate cell-phone use. Cell phones are implicated in significant and increasing numbers automobile crashes each year, resulting in a national trend toward legislating restrictions on cell phone use while driving.

Partly this is a social problem; some people should learn to be more considerate in the use of this technology. But part of the problem is technological; A cell phone is deaf and blind, and depends completely on the user to manage its state. Providing users better tools to manage the state of their phones, tools which require less of their attention and can do more automatically, can only help. We can't stop inconsiderate people from using the technology in an inconsiderate way, but we can help responsible people make better and safer use of cell phones.

Context Awareness

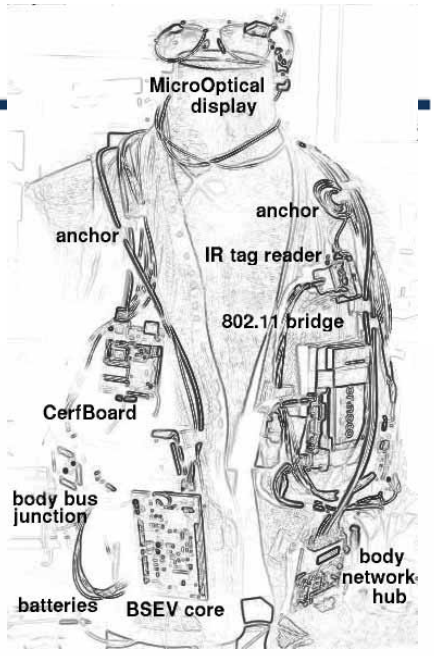
If it were possible to build a phone that could determine the user's circumstances or *context*, this information could be used to change the phone's behavior in useful ways. Such a *context aware* phone could automatically switch profiles when the user enters a restaurant, sits in the driver's seat of a car, *etc.* In the case of phone management, nearly all of the complexity lies in the sensing and determination of context. Once the context is known, very simple rules can produce behavior that appears quite intelligent.

Context awareness requires sensing and inference to determine the user's context. Both the sensors and the inference techniques must be chosen carefully in order to make the best possible use of the limited real estate and computing power available in a portable form factor.

Sensors

- GPS receiver
  - Outdoor location information
- Precision three-axis accelerometer
  - Precision three-axis accelerometer
  - Information about the user's activity state (walking, standing still, *etc.*)
  - Gestural input (planned)
- IR tag reader and IR active tags
  - Identify indoor door locations (meeting room, office, *etc*)
  - Recognition of special circumstances (sitting in the driver's seat of a car)
- Microphone
  - Recognize the user's voice and determine whether the user is in a conversation
- Bandwidth
  - Microphone band-limited to regions of interest for human speech
  - All remaining sensors are comparatively low-bandwidth
  - Managing bandwidth is important, because there is a direct correspondence between bandwidth, signal processing, and power consumption.

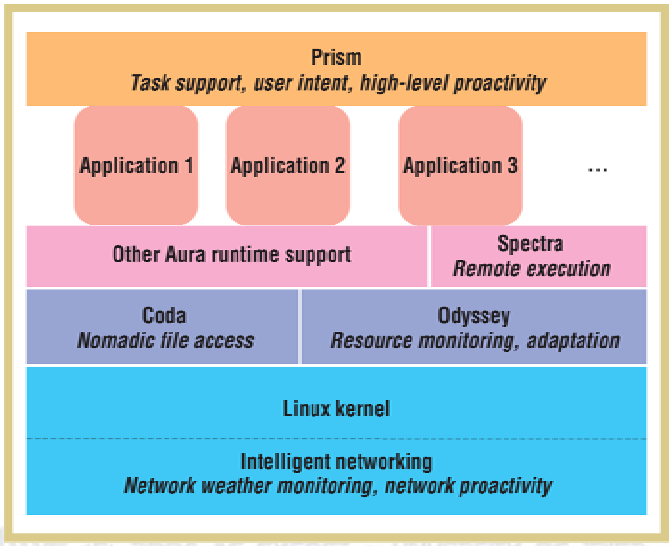
MIThril



Aura

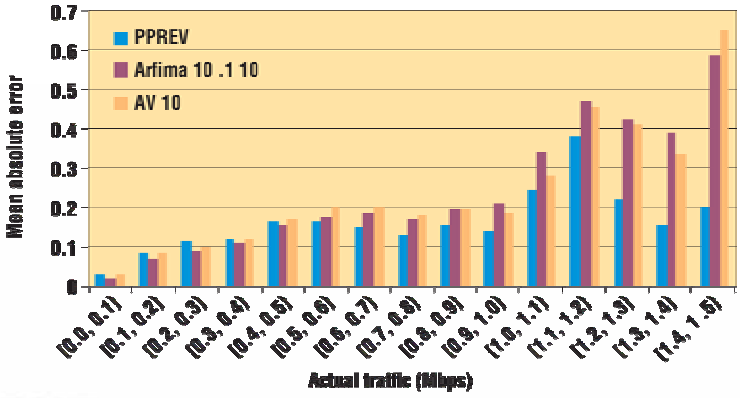
- CMU
  - D. Garlan, D.P. Siewiorek, A. Smailagic, P. Steenkiste
- Aura project
  - Minimize distraction on a user's attention
  - Adaption to user's context and needs
  - Wireless communication, wearable and handheld computers, smart space
- Concepts
  - Proactivity: Anticipate requests from higher layers
  - Self-Tuning: Observing demands and adapt performance and resource usage characteristics accordingly

Aura Architecture



Aura: Network Utilization Prediction

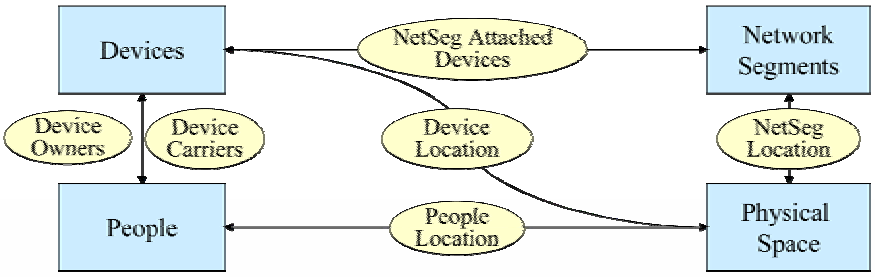
- Estimates of future available bandwidth
  - Server selection
  - Application demands



Aura: Context Information Database

- Context service of the Aura project
- Databases are very efficient at finding information and relationships
  - Powerful SQL query language
  - Query optimization to speed up common queries
- But context information doesn't fit readily in a regular database
  - Dynamic nature of information (and periodic updates)
  - Meta-attributes (precision of a sensor, etc.)
  - Structure of complex context information
- SQL-like interface to access a set of distributed contextual services

Aura: Contextual Services



- Entities: devices, people, networks, space
- Store information about entities and their relationship
  - Static information (mostly entities)
  - Dynamic information (relations)

Aura: Common Query Format

- Query arguments
  - List of selected attributes
  - Name of service to be queried
  - Desired information
  - Requirements such as time of update, confidence, …
  - Time limit (upper bound on execution time of query)
- Example: “Where is Bill?”
  - Attributes: Name “Bill”
  - Service: PeopleLocation
  - Expression: Location
  - Requirements: Room, Last 5 minutes
  - Time limit: 100 ms

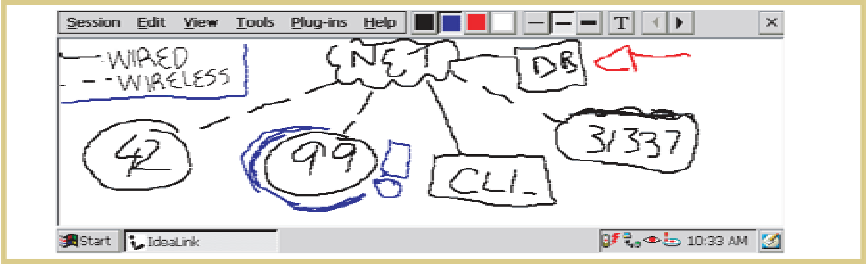
Aura: Portable Help Desk (PHD)

- Users may determine the location of teammates on campus and information about them
- Notification function
  - Closest available printer (☺)
  - Where to obtain food
- Spatial awareness
  - Relative and absolute position and orientation of user
- Temporal awareness
  - Scheduled time of public and private events

Aura: PHD (contd.)

- Visual interface
- audio interface
  - User: “Locate Bryan.”
  - Speech PHD: “Bryan is located in Hamburg Hall.”
  - User: “What is Bryan’s phone number?”
  - …

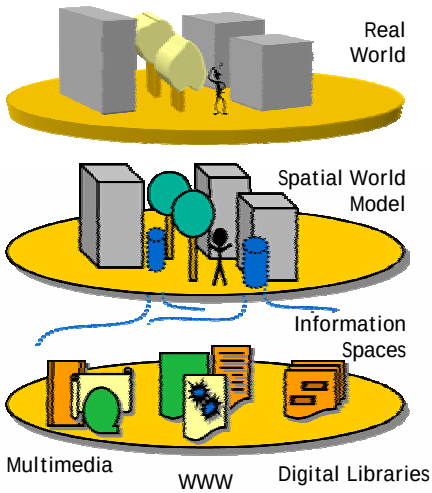
Aura: Idealink



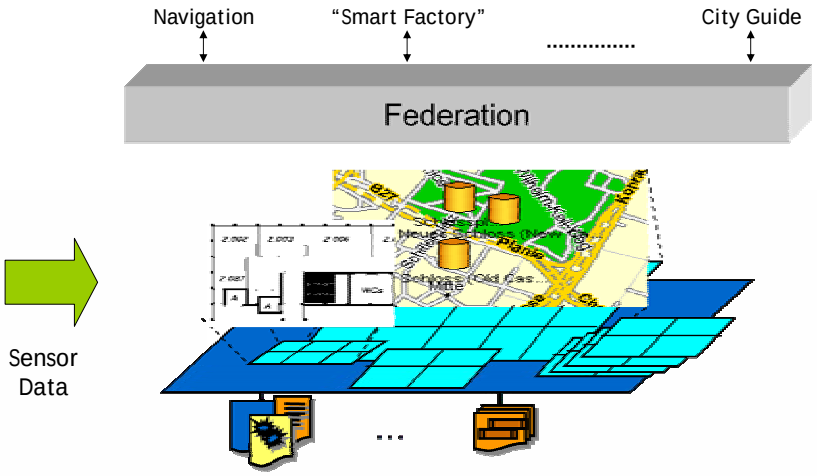
- Virtual colaboration environment
  - Planned and ad-hoc collaboration among mobile users
  - Easy access to information needed to initiate and conduct collaborative design meetings
  - Shared distributed whiteboard

Nexus

- Spatial world models for mobile context-aware applications
- University of Stuttgart
  - DFG-funded Sonderforschungsbereich
  - Started 2003
  - More than 30 researchers
- Goals
  - Concepts and methods to create and manage spatial world models
  - Context-aware applications and communications



Nexus: Federated Spatial World Models



Nexus Platform

- Federated, complex spatial model with stationary and mobile objects
- Real and virtual objects
  - Virtual information towers
  - Post it notes
  - …
- Context-aware information access and spatial queries
- Events triggered by changes in the model

Nexus: AWML

- Augmented world modeling language
- Object geometry (GML)
- Coordinate system
  - Absolute systems (e.g. WGS84, UTM)
  - Relative systems
- Symbolic descriptions
  - IDs, names, rooms, …
- Relationship between objects
  - Part-of relations
  - …

```
<awm>
  <object type="Room"
          NOL="nexus://...">
    <extension>
      <gml:st_polygon ...> ...
        <coord><X>5.0</X>
              ...
      </gml:st_polygon>
    </extension>
    <number>2.008</number>

  </object>
  ...
</awm>
```


Nexus: AWQL

- Augmented world query language
- Restrictions on the objects queried possible
  - Inside
  - Overlaps
  - Includes
  - Excludes
  - Closest
- Boolean expressions
- Generalization and aggregation rules (LoD)

```
<awql>
  <restriction>
    <and> <equal>
      <attr name="type"/>
        <nexusdata>restaurant
              </nexusdata>
    </equal>
    <equal>
      <attr name="nationality"/>
        <nexusdata>italian
              </nexusdata>
    </equal> </and>
  </restriction>
  <closest num="5" acc="10">
  ....
```

Summary

- Context is essential for modern applications
- Context Management
  - Context representation
  - Sensing and fusion of context
  - Virtual context defined by applications
  - Context sharing
  - Interoperability and extensibility
- Common understanding of primary context
  - Identity, location, time
- No commonly accepted standards yet
  - With some exceptions (SensorML, …)