Today

- Admin
- Teams
- Discussion Groups
- Quiz: Week 2
- Context-Aware Computing
- Team Project Brainstorming
Teams
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# Discussion Groups

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Mini Quiz
(week 2 content)

Context-Aware Computing
Motivation

• Modern computers alone are divorced from reality
  • Unaware of who, where, and what around them

• Context-Aware Computing
  • Making computers more aware of the physical and social worlds we live in
  • Breaking computers out of the box
Context-Awareness : Goal

• “Acquire and utilize information about the context of a device to provide services that are appropriate to the particular people, place, time, event, etc.”
  (Moran & Dourish, 2001)

• “Enhance the behavior of any application by informing it of the context of use.”
  (Dey, 2001)
Background

• Researchers at Olivetti Research and PARC pioneered Context-Aware Computing (1992, 1993)

• …under the vision of “Ubiquitous Computing” (a.k.a. pervasive, invisible computing)

• Many definitions of the term “context”
Context
What is Context?

• By example
  • Location, time, identities of nearby users …

• By synonym
  • Situation, environment, circumstance

• By dictionary [WordNet]
  • the set of facts or circumstances that surround a situation or event

• Problems:
  • New situations don’t fit examples
  • How to use in practice?
Definition: Context

- Shilit [94]*
- Schmidt [99]
- Dey [99, 01]
- Chen, Kotz (survey) [00]

* First to define the term “context-aware”

3 Categories of context:
- Computing context (connectivity, bandwidth, resources)
- User context (profile, location, nearby people)
- Physical context (lighting, noise, traffic, temperature)
Definition of Context (1/3)

- Schilit divides context into three categories:
  - Computing context
  - User context
  - Physical context
- Time is also important and natural context
  - Time context
  - => context history
Definition: Context

- Shilit [94]
- Schmidt [99]
- Dey [99, 01]
- Chen, Kotz (survey) [00]

“…knowledge about the user’s and IT device’s state, including surroundings, situation, and to a less extend, location”
Definition: Context

• Shilit [94]
• Schmidt [99]
• Dey [99, 01]
• Chen, Kotz (survey) [00]

“...any information that can be used to characterize the situation of entities (person, place, object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves.”
Definition of Context (2/3)

- Schmidt et al.: “knowledge about user’s and IT device’s state, including surroundings, situation, and to a less extent, location”

- Dey: “any information that can be used to characterize the situation of an entity”

- Entity: person, place, object that is considered relevant to the interaction between a user and an application
Definition: Context

- Shilit [94]
- Schmidt [99]
- Dey [99, 01]
- Chen, Kotz (survey) [00]

"...the set of environmental states and settings that either determines an application’s behavior or in which an application event occurs and is interesting to the user"
Definition of Context (3/3)

- Kotz: “the set of environmental states and settings that either determines an application’s behavior or in which an application event occurs and is interesting to the user”

- Active context: influences behavior of an application

- Passive context: relevant to the application, but not critical
Context Categories

- **Identity**: every entity has a unique id
- **Location**: position, spatial relationships (latitude/longitude, with friends, near a Starbucks, in the library)
- **Activity**: what’s happening in the situation (touring a museum, reading a book)
- **Time**: current time, duration of event, temporal ordering
Types of Context

- **Primary (low-level)**
  - Location, time, nearby objects, network bandwidth, orientation, light, tilt, vibration, sound, temperature…

- **Complex (high-level)**
  - “current activity”, complex social situations (e.g., in a meeting, giving a presentation)

- **Context History**

- **Context Properties**
  - E.g., Rate of change (user location vs. printer location)
Collection of Context

• **Explicit**
  • manual acquisition of context data from user(s)

• **Implicit**
  • automatic collection of context data from sensors (ideal)
Traditional View of Computer Systems

- Input
- Computer System
- Output

Context independent: acts exactly the same

Human in the loop
From Abstraction to Context Sensitivity

- Traditional black box view comes from the desire for abstraction
- This is based on several assumptions:
  - Explicit input/output: slow, intrusive, requiring user attention
  - Sequential input-output loop
- Move away from the black box model and into context-sensitivity
  - human “out-of-the-loop” (as much as possible)
    —> reduce explicit interaction (as much as possible)
Context as Implicit Input/Output

Context:
- state of the user
- state of the physical environment
- state of the computing system
- history of user-computer interaction
- ...

explicit input

Context-Aware System

explicit output
Context-Aware Computing

• Let computer systems sense automatically, remember history, and adapt to changing situations
• Reduced explicit interaction, more responsive
• Need to draw a boundary around the system under consideration
• To define “explicit” and “implicit”
### Why Context-Aware Computing?

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<th>Context Types</th>
<th>Human Concern</th>
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### Why Context-Aware Computing?

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Examples of Context

- Identity
- Spatial: location, orientation, speed
- Temporal: date, time of day, season
- Environmental: temperature, light, noise
- Social: people nearby, activity, calendar
- Resources: nearby, availability
- Physiological: blood pressure, heart rate, tone of voice
Context-Aware Computing
Context-aware Computing (1/3)

• Pascoe: taxonomy of context-aware features
  • contextual sensing
  • context adaptation
  • contextual resource discovery
  • contextual augmentation (associating digital data with user’s context)
Context-aware Computing (2/3)

• Dey: context-aware features
  • presentation of information/services to a user according to current context
  • automatic execution of a service when in a certain context
  • tagging context to information for later retrieval
Context-aware Computing (3/3)

• Kotz:
  
• Active context awareness - An application automatically adapts to discovered context, by changing the application’s behavior

• 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.
Active Badges

- Badges emit infrared signals
- Gives rough location + ID
- Teleport
- Redirect screen output from "home" computer to nearby computer
- Phone forwarding
- Automatically forward phone calls to nearest phone
Active Badges (cont’d)

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<td>C Turner</td>
<td>X307 Lab.</td>
<td>MON.</td>
</tr>
<tr>
<td>A Hopper</td>
<td>X434 AH</td>
<td>100%</td>
<td>R Want</td>
<td>X508 Meet. Rm.</td>
<td>77%</td>
</tr>
<tr>
<td>A Jackson</td>
<td>X308 AJ</td>
<td>90%</td>
<td>M Wilkes</td>
<td>X300 MW</td>
<td>100%</td>
</tr>
<tr>
<td>A Jones</td>
<td>X210 Coffee</td>
<td>100%</td>
<td>I Wilson</td>
<td>X307 Lab.</td>
<td>100%</td>
</tr>
<tr>
<td>T King</td>
<td>X508 Meet. Rm.</td>
<td>11:20</td>
<td>S Wray</td>
<td>X204 SW</td>
<td>11:20</td>
</tr>
<tr>
<td>D Lioupis</td>
<td>X304 R311</td>
<td>100%</td>
<td>K Zielinski</td>
<td>X402 Coffee</td>
<td>100%</td>
</tr>
</tbody>
</table>

12:00 1st January 1990

- Interface follow-me (location)
ParcTabs

- Active badge + wireless
- Rough location + ID
- Showing information of the room the user is in
- Help find resources
- Show all files in a directory when enter a room
- Locate others
- Different control choices in different rooms
- (location, time, nearby devices, file system state)
In/Out Board (Georgia Tech)

<table>
<thead>
<tr>
<th>Name</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gregory Abowd</td>
<td>In: 10:50am, Out: 10:50am</td>
</tr>
<tr>
<td>Jason Brotherton</td>
<td>In: 9:28am, Out: 9:28am</td>
</tr>
<tr>
<td>Anind Dey</td>
<td>In: 12:08pm, Out: 12:08pm</td>
</tr>
<tr>
<td>M. Futakawa</td>
<td>In: 12:00pm, Out: 12:00pm</td>
</tr>
<tr>
<td>Y. Ishiguro</td>
<td>In: 10:52am, Out: 10:52am</td>
</tr>
<tr>
<td>Rob Kooper</td>
<td>In: 5:26pm, Out: 5:26pm</td>
</tr>
<tr>
<td>Kent Lyons</td>
<td>Out: 12:27pm, In: 12:27pm</td>
</tr>
<tr>
<td>Jen Mankoff</td>
<td>In: 12:08pm, Out: 12:08pm</td>
</tr>
<tr>
<td>David Nguyen</td>
<td>In: 11:09am, Out: 11:09am</td>
</tr>
<tr>
<td>Rob Orr</td>
<td>Out: 1:25pm, In: 1:25pm</td>
</tr>
<tr>
<td>Maria Pimentel</td>
<td>Out: 5:54pm, In: 5:54pm</td>
</tr>
<tr>
<td>Daniel Salber</td>
<td>In: 10:14am, Out: 10:14am</td>
</tr>
<tr>
<td>Brad Singletary</td>
<td>Out: 2:50pm, In: 2:50pm</td>
</tr>
<tr>
<td>Khai Truong</td>
<td>Out: 1:25pm, In: 1:25pm</td>
</tr>
</tbody>
</table>
DUMMBO (Georgia Tech)

- Dynamic Ubiquitous Mobile Meeting Board:
  - Digitizing whiteboard to capture and access informal and spontaneous meetings
  - Capture ink written to and erased from whiteboard, and audio discussion
  - Activated when two or more people gathered around
  - Context: ID, time, location of whiteboard
Cyberguide

- GPS or infrared tracking
- Fairly precise location
- Display location on screen
- Predefined points of interest
- Automatically pop up if nearby
- Travel journal
- Keep log of places seen and photographs taken
- Context: location, time
Enhanced PDA

- Voice memo
- Hold like phone near mouth to start recording
- Portrait/Landscape
  - Physically rotate screen
- Tilt scrolling
  - Tilt instead of scrollbars
- Power management
  - Turn on if being held and tilted

Microsoft Research Hinckley et al
GUIDE
(University of Lancaster)

- Context: location through WLAN, user preference

General Information on Lancaster Castle

The Castle is owned by Her Majesty the Queen, who is the Duke of Lancaster. As well as being a fortification, the Castle is also one of Europe's longest serving operational prisons.

The Castle has not always existed in its present format but was built on the site of a Norman Fortress. The Castle is made up of several different buildings that have been erected at different times over the years. To find out more click here - Inside the Castle.

(Little castle image)

Inside, it is possible to see the Grand Jury Room, which contains some superb Gillyflower furniture, whilst...
Paper?
The EdFest System
User Tasks in a Mobile Environment

- **Locator [L]**
  - “Where am I?”
  - “Where is the lake?”

- **Proximity [P]**
  - “Where is the nearest bus stop?”

- **Navigation [N]**
  - “Get me to the clock tower.”

- **Event [E]**
  - “What is happening nearby?”
Location-Based Services (LBS)

- LBS are not always based on a user’s current position but also on past or future locations.

  • “Where is the National Stadium on the map?” [L]
  • “Which pubs may I find near this theatre on the map?” [P]
  • “Which other monuments can I visit near the castle?” [P]
  • “What’s on at the Shakespeare Theatre tonight?” [E]
  • “Get from my friend’s hotel to my current position?” [N]

  • “Note down that tonight’s restaurant was very cool.” [A]

[A] = Annotation
Positioning modes

- Positions may be defined by means of **how** they have been provided:
  - **Implicit** positions
    - tracking sensor (e.g. GPS, WiFi, …)
  - **Explicit** positions
    - point to the map (e.g. with a pen)
  - **Stored** positions
    - select a location through its placeholder (e.g. the name of a sight on a printed document)
Implicit Position

- **Current** user position as defined by a standard position sensor
- Used in most digital tourist guides to automatically track the users’ position

- **Examples:**
  - “What’s on nearby?”
  - “Where am I?”
Explicit Position

- **Arbitrary** position as defined by the user pointing to a map

- May be used in a “pre-visit” situation, where the user is planning future activities.

- **Examples:**
  - “What’s on at this location on the map?”
  - “Get me from this point to that building.”
Stored Position

- Position of a specific location as stored in a database
- Location accessed through the placeholder of a resource (e.g. a restaurant listed in a travel guide)

Examples:
- “What is near the pub listed in this travel book?”
- “Where is the stadium displayed in this picture?”
## Positioning modes for Location-Based Services

<table>
<thead>
<tr>
<th>Service</th>
<th>Explicit</th>
<th>Implicit</th>
<th>Stored</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Locator</strong></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Where am I?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Where is X?</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Proximity</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>What is near X?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Who is near X?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Navigation</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Get me (from X) to Y</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Event</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>What is going on at X?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Annotations</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Implementation: Interactive Paper Maps
Location-Based Services on the Map

What's on at...?
Get comments on...
Where am I?
Get me to...

[Map showing various locations and features]

[Image of a pen and earbuds]

[Map highlighting different areas and points of interest]
Interactive Paper Maps Architecture
Position Sensors

- Implicit position: **GPS device**
- Explicit position: **digital pen**
- Stored position: **application database**

Seamless switching between different positioning modes
Explicit Position: “What’s on at...”

- Find information about a specific venue
Explicit Position: “What’s on at ...”
Stored Position: “Where is ... on the map”

- Find the position on the map of a venue described in the event brochure
Stored Position

“Where is ... on the map”
Memory Aids

- **Forget-Me-Not**: Rank Xerox
  ParcTab recording where its user is, who they are with, whom they phone, etc. in a database for later retrieval
- **StartleCam**: MIT Media lab.
- **Skin conductivity sensor** triggers taking of images and transmitting to remote server
Other Applications

• Shopping assistant (location)
• Smart floor, active floor
• Office assistant from MIT Media Lab. (activity, schedule)
• …
Today?

Pair up and look on the web
Context awareness in your team project?
Telling Traces

Deborah Estrin
UCLA Center for Embedded Networked Sensing (CENS)
Joint work with many collaborators at UCLA

Enabled by \( >3 \times 10^9 \) mobile phone users, increasingly with GPS, imagers, rich UI, programmability, and ubiquitous connectivity

https://www.youtube.com/watch?v=WZTg ysBWGg
Next Steps

• Readings to discuss on Thursday


Mid-Term Presentations

- Tuesday next week: preparation
- More info on Piazza
- Thursday next week: presentation
- More info on Piazza
Additional Material
(not part of the weekly evaluation)
Context-Aware Computing: Taxonomy
Taxonomy of Context-Aware Apps

- Triggers
- Metadata Tagging
- Reconfiguration and Streamlining
- Input specification
- Presentation
Triggers

• On X do Y

• "Notify doctor and nearby ambulances if serious health problem detected"

• "Remind me to talk to Chris about user studies next time I see him"
Metadata Tagging

- "Where was this picture taken?"
- "Find all notes taken while Mae was talking"
- Memory prosthesis
- Stick-e notes: University of Kent
  - Stick-e note: attaching notes to a context, later trigger the node when context occurs again
  - Programming environment based on stick-e: Triggering, execution, and sensor components
Reconfiguration and Streamlining

- Telephone forwarding and Teleport
- Turn off cell phone in theaters
- Automatically adjust brightness / volume
- Automatic file pre-caching
- Select modes in multimodal interaction
- Multimedia / Bandwidth adaptation
Input and Presentation

- Input specification
  - Send mail only to people in building now
  - Print to nearest printer
  - "Find gas stations nearest me"
- Presentation of plain contexts
  - Current location
  - Idle?
  - Currently in?
  - Contextual info about objects
  - Proximate selection
Context-Aware Applications
Design Process of Typical Context-aware Applications

1. Specification
2. Acquisition and Representation
3. Delivery/Distribution
4. Reception and Storage
5. Action (the application)
Design Process: Specification

- Context to use
- Context behaviors to perform
- Key step in design process: problem specification
Design Process: Acquisition

- Install relevant sensors
- Sensors: infrastructure or personal artifacts
- Where to sense?
- How often to update and report?
- Context representation
- Store context
Design Process: Delivery/Distribution

- Contexts typically captured remotely from applications at different time

- Context captured in sensor-rich environment or device may need to serve multiple applications

- => Need to deliver and distribute context to multiple, remote applications

- Infrastructure or middleware support
Design Process: Reception

- Application locates relevant sensors/contexts
- Service discovery
- Requests contexts via queries, polls, notifications
  - Query language, event-notification mechanism
- How often to request?
- Additional interpretation/abstraction/processing
  - Collection, aggregation, filtering, correlation, fusion,...
Design Process: Action

- Combine received contexts with previous contexts and system/application states for further analysis
- Perform actions based on the analysis results
- May treat context collection/processing as a separate service
Sensing the Context
(1/3)

• Location:
  • Outdoors: GPS
  • Indoors: IR, RF, ultrasonic, camera (cellular and non-cellular)
  • Hybrid: WiFi, Bluetooth

• Issues:
  • Heterogeneous sensors with uncertainty and conflicts (sensor fusion)
Sensing the Context (2/3)

- Low-level contexts beyond location
  - Time: time-of-day (with calendar)
  - Nearby objects
  - Network bandwidth
  - Orientation
  - Others: photodiode (light), accelerometer (tilt, vibration), microphone, sensors for temperature, pressure, gas, etc.
- Issue: sensors in mobile devices or infrastructure => direct vs. indirect awareness
Sensing the Context (3/3)

- High-level contexts: user's activity
- Camera technology and image processing
- Consult calendar for what user is to do
- Combine low-level sensors, e.g., using rules
- How about emotional contexts?
- Context changes: subscription-notification
- Polling rate?
Quality of Contexts

• What context is important? Always and in different situations?

• Quality:
  • Coverage, resolution, accuracy, confidence, reliability, frequency, timeliness

• Self-contained vs. infrastructure-supported
  • Smartphone doesn't need location sensors if it can ask nearby sensors to approximate

• Standards for sharing components?
Modeling Contexts

- Location model:
  - Symbolic: Active Badge, symbols
  - Geometric: GPS, coordinates
- Environmental model: relationship between ...
  - Locations: hierarchical, containment, distance
  - People: friend, family, hierarchy
  - Devices?
Context Specification

- Need to express context about and relationships between People, Places, Things
- Predicates
  - Identity (Who is…? What is…? Is with…?)
  - Location (Near? Nearest? Distance? Path?)
  - Activity (Is busy? Is in meeting? Current task?)
  - Time (In past? In present? In future? On date?)
- Some of this vocabulary done by Schilit
  - Implicitly encoded in his APIs
  - One goal is to extend his work in spec language
  - Another is to make it extensible for future context types
Context Specification

• Common parameters
  • Max number of results wanted
  • Return name
  • Return data type (e.g. String, List, Table)
  • Minimal probability of correctness desired
  • Relevant sensor input requestor has

• Event parameters
  • Event rate (e.g. at most 1 event per second)
  • Event callback (e.g. RPC, socket port)
  • Max number of events desired
  • Granularity of change (e.g. 1 meter)
Context Interpretation

- Sophisticated applications require higher level forms of context
  - Fusion
- Ambiguity:
  - Sensors not 100% reliable, e.g. confidence value
  - Precision / Accuracy / Granularity
- Different ways to deal:
  - Improve inference
  - Probability/fuzzy model
  - Bring the user into the loop
System Issues (1/2)

- Programming model
  - Programming the physical world
  - Unreliable sensors, recognition algorithms, plus standard distributed computing issues
- Interoperability
  - Sensors, services, and devices
  - Useless if everyone has proprietary / custom systems
  - Need standard data formats, protocols, and frameworks
  - Varying capabilities of sensors, services, and devices
- Evaluation
System Issues (2/2)

- May need a middleware layer to decouple applications and context sensing
- Collect raw context, translate to application-understandable format, disseminate it
- Centralized context server
- Distributed architecture
Intelligence

• Who is smart? User or system or both
• Who makes the decisions on what actions to take?
• Tradeoff between user cognitive load and effort to make system “smart”
People Issues

- Avoiding embarrassing situations
  - Active Badges + bathrooms
  - Inconvenient phone forwarding
- Avoiding dangerous situations
  - Need to take into consideration cost of mistake
  - Smoke alarms when cooking
  - Lights that turn off when you're still there
  - Woman locked in "smart toilet stall"
- Will adding more context really help here?
People Issues

- Making it predictable and understandable
  - Setting preferences
  - "I want my cell phone to ring except in theaters and when I'm in a meeting unless…"
  - Why the heck did it do that?
- Privacy
  - What does the computer know about me? What do others know about me?
  - Capturing/collecting lots of information about people, places and devices
  - People uncomfortable when don't know what is being collected and how it's used
Operational Definition of Context

“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 the application themselves.”

[Dey and Abowd, 2000]
Context-Aware Applications

“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.”
Sources

- Chung-Ta King, Context-aware Computing: Basic Concepts, National Tsing Hua University
- Omar Khan, Context and Context-Aware Computing, UC Berkeley
- John Kembel, Toolkits for Ubiquitous Computing, Context Awareness, and CSCW, CMU