Mobile Computing: the Next Decade

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Early-90s Dream of Mobile Computing
Phenomenal Hardware Progress

Compaq Luggable  
~ 1987

Compaq iPaq  
~ 1999

IBM Linux Wristwatch  
~ 2000

Google Android  
~ 2008

NCR WaveLan  
915 MHz  
ISA  
~1990

802.11b PC cards  
~ 1999  
~2003
What Will Inspire and Drive Mobile Computing Research in the Next Decade?
Emerging Themes

1. Mobile devices as rich sensors

2. Near-real-time data consistency

3. Opportunism

4. Outreach
Rich Mobile Sensing

Cameras integrated with almost every mobile device today
• rich sensing devices (2D CCD array, temporal if video)
• sound capture is another example (1D, temporal)

“Rich” → high-dimensional and complex
• requires extensive processing by human/software to extract value
• not simple scalar values (e.g. temperature, salinity, light intensity, …)
• data capture easy but interpretation difficult

Sensing community fixated on “smart dust” vision (SenSys, MobiHoc, …)
• cheap, disposable motes + TinyOS
• simple scalar values, little on-board processing, little storage
• dominance of ad hoc wireless networks

“Brilliant rock” better metaphor for mobile sensing than smart dust
• more processing, memory, storage, networking
• but captured data also requires more intense processing
• too expensive to be disposable
• energy considerations still dominate, but more tractable
• typically include human in the loop
Example: Lost Child in Crowd
Macy’s Thanksgiving Day Parade
Lost Child Found!

Here she is!
Observations

**Opportunism**

- pictures were taken for some other reason
- captured data rich enough to contain “other extraneous stuff”
- the “other stuff” is focus of someone else’s search later
- how do you index data of this kind?

**Near-real-time data consistency**

- only pictures taken after child was lost are useful
- bounds on geographic region too (speed of motion)
- implications for caching and data consistency checking?
Example: GigaPan Remapping for Disaster Recovery
GigaPan Zoomable Images

Hanauma Bay, HI; May 2008
(5.6 gigapixels, 378 images)

GigaPan Robots
GigaPan of Hanauma Bay, HI
Potential Value in Disasters

Port Au Prince, Haiti; January 29, 2010
(225 images hand-captured by reported; stitched after return to the US)
What Mobile Computing Architecture Do We Need to Support These Classes of Applications?
3-level Mobile Computing Hierarchy

Historically: 2-level hierarchy (client and server)

New proposed architecture: 3-level hierarchy

- cloud
- cloudlet
- mobile device

Cloudlet provides compute resources for “cyber foraging”

- offloads intense computations (e.g. GigaPan stitching, image search)
- low-latency 1-hop wireless access for human-in-loop interactions
- allows “cellular” style computational coverage for small regions
Cloudlet = Small Cloud Nearby

Cloudlet = (compute cluster + wireless access point + wired Internet access + no battery limitations)

→ “data center in a box”
## Cloudlet vs. Cloud

<table>
<thead>
<tr>
<th></th>
<th>Cloudlet</th>
<th>Cloud</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>State</strong></td>
<td>Only soft state</td>
<td>Hard and soft state</td>
</tr>
<tr>
<td><strong>Management</strong></td>
<td>Appliance model: self-managed; little professional attention</td>
<td>Utility model: professionally administered, 24x7 operator coverage</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td>“Data center in a box” at customer premises</td>
<td>Machine room with power conditioning and cooling</td>
</tr>
<tr>
<td><strong>Ownership</strong></td>
<td>Decentralized ownership by local business</td>
<td>Centralized ownership by Amazon, Yahoo!, etc.</td>
</tr>
<tr>
<td><strong>Network</strong></td>
<td>LAN latency and bandwidth</td>
<td>Internet latency and bandwidth</td>
</tr>
<tr>
<td><strong>Sharing</strong></td>
<td>Few users at a time</td>
<td>100s to 1000s of users</td>
</tr>
</tbody>
</table>
Cloudlets in Disaster Scenarios

- Gigapan Imaging Robot
- Android Phone
- Nokia N810 Tablet
- Lenovo Laptop
- Low-latency high-bandwidth wireless network
- Cloudlet near rescue workers
- to other cloudlets and Internet

Cloudlet near rescue workers

Low-latency high-bandwidth wireless network

Gigapan Imaging Robot

Android Phone

Nokia N810 Tablet

Lenovo Laptop

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Cloud Computing in the Face of Disrupted Internet Connectivity

Internet-based Cloud Resources

Emergency Internet Gateway

weak Internet connectivity

Disaster Area

Cloudlet 1

Cloudlet 2

Cloudlet 3

Cloudlet 4
Closing Thoughts

*Embrace challenging real-world applications*

- rich crowd-sourced mobile sensing
- developing countries
- disaster relief
- environmental sensing (Gulf recovery?)
- ...

*Drivers of mobile computing advances in the next decade*

- identify common themes and requirements
- distill into mobile architectures, system support and infrastructure